# THE STARS AND THE MIND

Since quite an early period in man's history the way in which he has looked at the astronomical universe has had a considerable influence on his manner of regarding life as a whole. The other sciences, the arts, the religions, have all in their turn been influenced by man's opinion of the place of the earth in the universe—and this is the fundamental astronomical problem. Consequently Dr. Davidson's new book, in which he develops the theme of the influence of astronomy on human beliefs, is an important one. It is virtually the first work to appear in recent times which embodies all the latest developments in astronomy, and attempts to link those developments to the more general field of philosophic thought. For that reason it is likely to advance its author's already wide reputation as a scientific and philosophic popularizer of the first rank.

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FROM ATOMS TO STARS (1944 AND 1946)
THE GYROSCOPE AND ITS APPLICATION (Editor; 1946)
THE MID-TWENTIETH CENTURY ATOM (1946)

# THE STARS AND THE MIND

A Study of the Impact of Astronomical Development on Human Thought

BY

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# PREFACE

In this book I have given a *résumé* of the development of astronomical science from the earliest periods of man's history up to recent times, and also of its impact on human thought and action. It has been impossible to separate such a *résumé* from the influence of astrology—a superstition which has been very closely associated with astronomy and which has so often exercised a pernicious effect on the lives of people. Among some of the early races astrology had a profound influence, and official astrologers at the Royal Courts frequently advised the rulers on policies connected with both the internal and external affairs of the State. In some respects this astral fatalism, which naturally resulted from the belief that a man's character and also his future were decided by the ruling constellation at the time of his birth, was detrimental to social progress, but on the whole it does not always appear to have been so baneful as we might expect. We cannot help admiring the wonderful strides that were made in the social life of the Babylonians, among whom astrology had an important influence, but to what extent the lives of the ordinary people were affected by astrology is a matter of doubt and conjecture. An archæologist thousands of years hence, who chanced to unearth some of our twentieth-century books and Press publications of a certain type, might imagine that most people had regulated their lives in accordance with the predictions of astrologers, but his conclusions would be far from the truth. It is possible that a large portion of the people in early civilizations was unaffected by astrology, which was reserved for those who could afford to pay liberally for indulging in this cult.

The present survey shows how the conception of a continuous interference and control of the universe by some external power gave way to a nobler and higher conception of an inherent natural order. A mechanical view of the universe replaced the old and cruder view, which was quite consistent with arbitrary and vindictive acts on the part of a petty-minded ruler. The modern astronomer pursues his research on the assumption that such acts

do not occur, and without this assumption he could not with any degree of confidence continue his investigations.

Within recent times a remarkable development has occurred, which seems to leave a loop-hole for a belief in a non-mechanical universe. Progress in atomic physics has, in the opinion of some physicists, dealt a severe blow to the view that the universe is a closed system. In the opinion of the writer this view is not very easy to defend, but the controversy still continues, and probably will continue for a long time.

Towards the end of the work the influence of astronomical development on the Christian faith is considered, and its far-reaching effects are dealt with. While restatement of a number of doctrines has been made from time to time, it is questionable whether any of them have gone far enough, and it is certain that in many cases there has not been sufficient candour in the new presentation. More honest admissions are essential at present, when problems arising out of the complexities of modern civilization are baffling the best minds. Our conception of the universe is so utterly different from that of our forefathers that readjustment of our views on moral, social, and international problems is necessary. It must be admitted, however, that it is not easy to prescribe the exact lines along which such readjustments should be conducted, and for a long time many of the problems which vex the souls of men must inevitably prove intractable.

It should be pointed out in conclusion that astronomical developments only are dealt with, except for a brief reference to recent research in physics, with which astronomy is closely associated. While this naturally limits the scope of the book, it is believed that it will render it more readable to the general public than a more comprehensive work which included in its compass developments in other branches of science.

1946. M. DAVIDSON.

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## CHAPTER I

# CHINESE ASTRONOMY

LONG before the beginning of civilization among Western nations astronomy had been carried to a certain degree of perfection among the Chinese, though, as will appear later, some of their conceptions regarding the heavenly bodies, as well as some of their observations, must be considered crude in the light of modern developments. Their existing records, the authenticity of which is asserted by the Chinese, have been studied by European scholars and have been acknowledged by some of the most eminent of them to be authentic. Later records, which, in addition to containing a considerable amount of information of an historical nature, deal in many parts almost exclusively with astronomy, afford much useful information to the modern astronomer. This applies more especially to records of eclipses and to the observation of comets, both of which seem to have proved interesting phenomena to the Chinese astronomers. Their descriptions of the paths of comets among the stars are often very minute and show careful observation, and the same applies to the records of the times and appearances of these bodies.

According to *The Annals of the Empire*, Fou-Hi (or Fo-Hi), who lived about 2580 B.C., gave to his people a rule for reckoning time. He knew how to find the period of the solstices—an epoch when sacrifices of animals were made. Although many other nations offered human sacrifices at certain seasons of the year, there is no record that the Chinese indulged in this barbarous practice. It must not be assumed that Chinese astronomers, on the whole, appreciated the beauties of astronomy in that remote period, and Fo-Hi actually records this fact for future generations. We might ask whether Western people to-day appreciate, on the whole, the beauty of astronomy, except in so far as it is applied to practical ends.

The Emperor Hwang-Te (2698–2598 B.C.) is said to have been responsible for the erection of a great observatory and to

have undertaken the reform of the calendar. He is supposed to have introduced the system of reckoning chronology by the cycle of 60 years—a system which continued in use until comparatively recent times. Astronomers were directed to observe the sun and the moon and to follow the movements of Mercury, Venus, Mars, Jupiter, and Saturn, which were the then known planets. Although Chinese astronomers seem to have been careful about some observations, in certain ways they showed great carelessness. Thus it is said that Yu-Shi, an astronomer who lived during the reign of Hwang-Te, asserted that the pole star did not move. In his time the pole star was $\alpha$ Draconis, which was 2° from the pole (the precession of the equinoxes is responsible for various stars being close to the pole at different epochs), and the observations which decided that $\alpha$ Draconis was immovable could not have been very accurate.

The discovery of the lunar cycle of 19 years was made at this time, although it is commonly believed that Meton, the Athenian astronomer, discovered it first about 433 B.C. During 19 years there are 235 lunations, and hence new moons and full moons during this interval of time will repeat themselves about the same dates in successive cycles. It is interesting to know that the planetarium, which represents the movements of the stars, and of which America possesses five to-day, was constructed first by direction of Hwang-Te. While many of these discoveries and inventions rest largely on Chinese tradition, and not on absolutely trustworthy authority, the following observations alleged to have been made in the reign of Chuen Kuh, a grandson of Hwang-Te, are interesting as showing the authenticity of some at least of the early Chinese annals.

During the reign of Chuen Kuh a conjunction of five planets is said to have taken place in Ying Shih, which we know was one of the Chinese stellar divisions, determined by $\alpha$, $\beta$, and other stars in Pegasus, extending north and south from Cygnus to Piscis Australis, and east and west 17°, comprising portions of the modern signs of Capricornus and Aquarius. Astronomers are able to compute the times of conjunctions of planets, and it has been shown that a conjunction of the five planets took place on

February 29, in the year 2449 B.C. As Chuen Kuh reigned 78 years, from 2513 to 2436 B.C., there is strong presumption of the authenticity of these early Chinese annals. It might be suggested, as against this view, that more modern Chinese astronomers computed the places of the planets at that time, but there is no evidence that Chinese astronomers were capable of doing this before they had intercourse with European astronomers.

Although the readers of this work are assumed to possess a certain amount of astronomical knowledge, it is possible that some may not understand what is meant by a conjunction of planets. Two planets are said to be in conjunction when they make their nearest approach before passing each other in their courses. They are usually considered to be in conjunction when they have the same *longitude*, and if all the planets moved exactly in the ecliptic during their orbital motions round the sun, one would appear to pass behind or in front of the other when their longitudes were the same. As the orbits of the planets are inclined at various angles to the plane of the ecliptic, the planets generally have different latitudes when their longitudes are the same; hence there is a small distance between them. The conjunction of five planets is not very common, and the record of the observation by Chinese astronomers of the conjunction in 2449 B.C. has the appearance of authenticity.

The *Shoo King*, one of the five classical works which the Chinese consider to be the oldest of their books, was revised by Confucius in the sixth century B.C., and contains some interesting astronomical information. In this may be noticed the instructions of the Emperor Yaou, who ascended the throne in 2356 B.C., to his astronomers designated He (or Hi) and Ho. These are not the actual names of the astronomers, but of two families under whose supervision were placed such matters as the arrangement of the calendar for the year, the making of all necessary observations, the carrying out of the computations, etc. It is believed that their office, like that of many others in Oriental countries, was hereditary. Yaou is described as commanding He and Ho "to observe the heavens, to compute the calendar, to form an instrument by which the motions of the sun, moon, and twelve signs

might be represented, and with due respect to impart information respecting the seasons to the people."

The comment on this passage is interesting, throwing some light on the astronomical knowledge of the Chinese at the time. Among other items of information, we are told that the sun represents the male, or superior, principle of nature, and the moon the female, or inferior principle. This information, which is typically Oriental, need not surprise us, and Western nations have not so long emerged from this discriminating view of the relative merits of the sexes that they can afford to be hypercritical of the Chinese. Obviously there was no suspicion of the heliocentric view of the solar system, because it is stated that the sun passes round the earth in one day, and that the moon is in conjunction with the sun at each lunation. The heavens are compared to a piece of cloth in the loom, the stars forming the warp, and the planets the woof. This comparison is not altogether fanciful, because it indicates roughly the paths of the planets among the stars. A word "Shin," used in Chinese astronomy, is explained to mean the twelve places in which the sun and moon are in conjunction, and in some respects it corresponds to our twelve signs of the zodiac.

Many other narratives concerning the activities of the astronomers in the days of Yaou could be recounted, but only a few of them have any value for us at present. It is said that four astronomers were sent to the north, south, east, and west respectively, with the object of seeing the stars which indicated the equinoxes and solstices; the one who was directed to go to the south was told to observe the length of the sun's shadow and thus ascertain the middle of summer. It is fairly obvious that this refers to the observation of the summer solstice by ascertaining when the shadow cast by a gnomon was shortest. It appears that the length of the solar year in the time of Yaou was established as 365¼ days, and if the records in the *Shoo King* are correct, the Chinese astronomers were able to carry out a number of computations which were necessary to maintain the seasons in their true places.

During the reign of Tchong-Kong an eclipse of the sun took

place, in 2158 B.C., and the official astronomers Hi and Ho (probably descendants of the Hi and Ho mentioned previously) were condemned to death because they failed to predict the occurrence. Another story relates that they both got so drunk that they failed to observe the eclipse from the place where they had calculated it would be visible. An epitaph was composed on these unfortunate astronomers and appeared in *The Observatory*, 1894:—

> Here rest the bones of Ho and Hi,
> Whose fate was sad yet risible,
> Being hanged because they did not spy
> Th' eclipse that was invisible.
>
> Heigh-ho! 'tis said a love of drink
> Occasion'd all their trouble.
> But this is hardly true, I think,
> For drunken folks see double.

If, as seems probable, the office of astronomer was hereditary, Hi and Ho must have regretted accepting the heritage.

Observations of comets by Chinese astronomers have proved helpful in recent times in the identification of a number of these objects. In 134 B.C. the appearance of a comet led Hipparchus to undertake the compilation of his catalogue of stars. A number of astronomical text-books have asserted that the object was not really a comet, but a nova or new star; but the late Dr. J. K. Fotheringham showed that it was a comet. The appearance of this comet, which is also recorded by the Chinese, preceded the birth of Mithridates. A similar object, which was seen fourteen years later, was supposed by the Chinese to be the same comet; and while some historians have treated these records as mythical, intended to glorify Mithridates, they were not aware at the time of the corroborative evidence from China.

The best known of the periodic comets—Halley's Comet—was definitely observed by the Chinese in 240 B.C., and was possibly observed by them in 467 B.C. It was also observed by them a number of times since 240 B.C. on its successive returns, after periods of about 76 years. The Emperor Che Wang, who reigned at the time of the first date mentioned above, is said to have ordered all books to be destroyed except those which related to agriculture, medicine, and astrology. These were the only

sciences which he considered useful to mankind, and it is believed that by this decree many important astronomical collections were lost.

A careful examination of the records shows that Chinese astronomy consisted almost entirely of observational work which led merely to the knowledge of some isolated facts. No attempt at systematization appears to have been made, though we must give them credit for some observations which showed remarkable skill for a people with very crude apparatus. Thus, the obliquity of the ecliptic was determined by them, about 1100 B.C., to be $23° 54' 3{\cdot}15''$—a result which is now considered to have been very accurate. One wonders how the Chinese were able to derive results which were apparently correct to a small fraction of a second of arc, but presumably this alleged accuracy must not be taken too seriously. In spite of such accurate work with inferior equipment, the more we know about the astronomy of the Chinese the more does it take its place as rather insignificant. It must not be forgotten that the Chinese continued to observe the heavens century after century without making any advance in theoretical knowledge, and improvements in methods and equipments in later times have been largely due to foreigners.

The Jesuit missionaries, sent to China in the seventeenth century, spread accounts of the wonderful attainments of the inhabitants, and it is possible that they were misled by a superficial knowledge of the scientific progress of the Chinese. On the other hand, it has been suggested that they considered it expedient to avoid arousing animosity among the people whom they were trying to convert, and for this reason they were prepared to exaggerate the true facts. The Celestials were very jealous about their attainments, and foreigners were not always made welcome, even when they brought certain benefits of Western civilization. Nevertheless, this spirit was often so far relaxed that protection was afforded to strangers who introduced much in science and in other ways that added to the amenities of life.

It now remains to inquire into the influence, if any, of astronomy on the social and religious life of the Chinese.

When we penetrate into remote Chinese history we find that

the earliest rulers attempted to conciliate the spirits of the mountains and rivers by sacrifices or offerings of food. In the course of time either the ruler or the high priest co-ordinated the movements of the heavenly bodies with human affairs, so that the alternations of light and darkness suggested the conception of sky and earth, summer and winter, soul and body, life and death, and even man and woman. This conception has permeated Chinese astrology, religion, and philosophy throughout the ages, and probably survives in many parts to-day; though one can scarcely speak with confidence on the outlook of the average Chinaman, after years of devastating war in which millions have perished from battle, plague, or famine. The best standard versions of Chinese works were kept at the Royal Courts during the later dynasties, and the keeper of the archives was the astrologer—a fact which shows how closely the movements of the heavenly bodies were associated with human vicissitudes. From the earliest time religion in China was very largely a system of obligations towards the State organism as part of the organism of Nature. An interesting light is thrown on this subject by a quotation from the *Book of Changes*—one of the Chinese "classics":—

> Regard the divine road of Heaven, and the unerring sequence of season. The holy man sets his teaching by the divine road, and the Empire submits accordingly.

The spiritual teaching of Lao-Tse, associated with the Taoist religion, is indissolubly connected with the universe and with man, and the same applies to the spiritual teaching (in so far as such can be discerned) of Confucius. In contrast to the Christian and other religions, miracles are never even suggested, and there is hardly any conception of the after-life. Saving one's soul is utterly alien to their teaching, and indeed the idea of saving one's self is indirectly condemned as unworthy. Sacrifice of self, in the highest sense, is advocated, but this is completely dissociated from any love of God. In fact, rather than "love for God," respect for the unknown is commended.

Although the keepers of ancient Chinese records, like the

Chaldeans and Egyptians, were unable to separate human events completely from celestial phenomena, it would scarcely be correct to say that the study of celestial bodies was solely responsible for their outlook and teaching. Many phenomena besides those associated with the heavenly bodies played their part, and the Taoist systems, like other Chinese codes of conduct, were bound up with various mysterious forces of nature. It seems highly probable, however, that if the Chinese had speculated more and had formed theories regarding the heavens, thus anticipating some of the Greek astronomers, or even those of many centuries later, their discoveries might have modified considerably their ethical systems and also their religious beliefs. It was very unfortunate that the astronomy of a race with such an ancient civilization, possessing men with scientific inclinations and capable of conducting prolonged and often accurate observations of the stars and planets, should have crystallized so soon and have failed to assimilate new ideas, except under the stimulus of the hated "foreigner." If only they had proved more adaptable, the course of astronomy, and probably of other sciences as well, would have had a different history. But the story of the human race is a record of wrong turnings or of failures to embrace valuable opportunities. Often, at what might have been a turning-point in history, the wrong direction was chosen, and only after the lapse of millennia did the rejected opportunity recur.

## Note on the Gnomon

If a stake is driven vertically into the ground and we observe the changing direction of its shadow cast by the sun, we can gain a rough idea of the time of the day. Such an instrument is called a gnomon (from the Greek *gi-gnosco*, I know); but for various reasons the shadow of a vertical stake is very unsatisfactory, and a great advance was made when the gnomon was set up so that it pointed to the pole of the heavens. In such circumstances we have a true sun-dial. In the Book of Isaiah, Chapter XXXVIII, we read about the dial of Ahaz, the father of Hezekiah, and as Ahaz commenced his reign about 742 B.C. we have a reference to

an early form of solar time indicator. It is impossible to say, however, what was the particular form of Ahaz's sundial.

A sketch of an ancient stele is shown in Fig. 1.

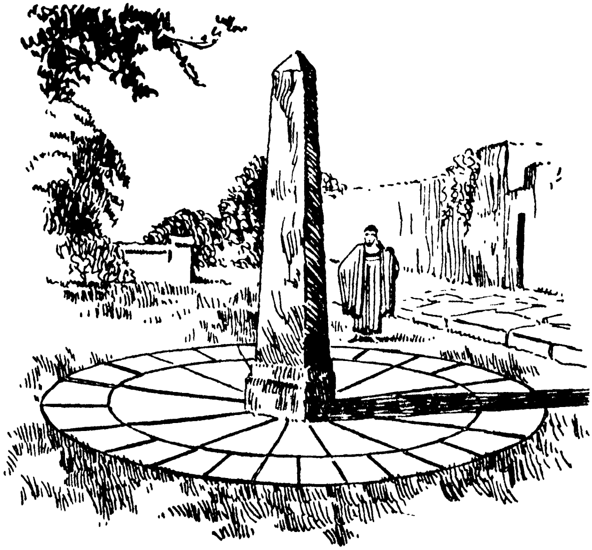


FIG. 1.—ANCIENT STELE USED AS A GNOMON.

This monument is supposed to have been used to follow the course of the seasons by noting the length of the shadow cast by the sun at midday.

## CHAPTER II

# THE CHALDEANS

ACCORDING to the testimony of the Greek historians, the earliest traces of astronomical knowledge are found among the Chaldeans and the Egyptians. No special credit is due to the Chaldeans for their astronomical knowledge; the credit, if any is to be assigned, must be given to their climate, which afforded wonderful facilities for the observation of the heavenly bodies. In addition, the earlier inhabitants were largely engaged in a pastoral life and had a considerable amount of leisure for studying the stars. They had also a stimulus emanating from their belief in astrology and their desire to understand the relation between the aspects of the stars and human affairs. In spite of their opportunities, the Chaldeans formulated no theories regarding the movements of the heavenly bodies; and although they were able to make predictions with a certain amount of accuracy, these predictions were based entirely on empirical evidence. Thus, by observing eclipses over many centuries (about nineteen, according to some authors), they had discovered the cycle of 235 lunations in 18 years 11 days, known as the Chaldean Saros. If a record be made of all the eclipses which occur during one of these cycles of 18 years 11 days, they will be found to repeat themselves approximately, though the solar eclipses will not be visible from the same parts of the earth when the cycle is repeated.

Although the Chaldeans did not indulge in theories, we must give them credit for many correct observations. They delineated the zodiac, and invented the gnomon and the clepsydra. The former was used for marking the direction of the shadow thrown by the sun, and had many forms.[1] The invention of the hollow dial cut in a block of stone is attributed to Berosus, the Chaldean philosopher, who lived in the fourth century B.C. A fixed bar cast a shadow on its concave surface, which was divided by lines to mark the hours of the day. Many other forms of gnomon were

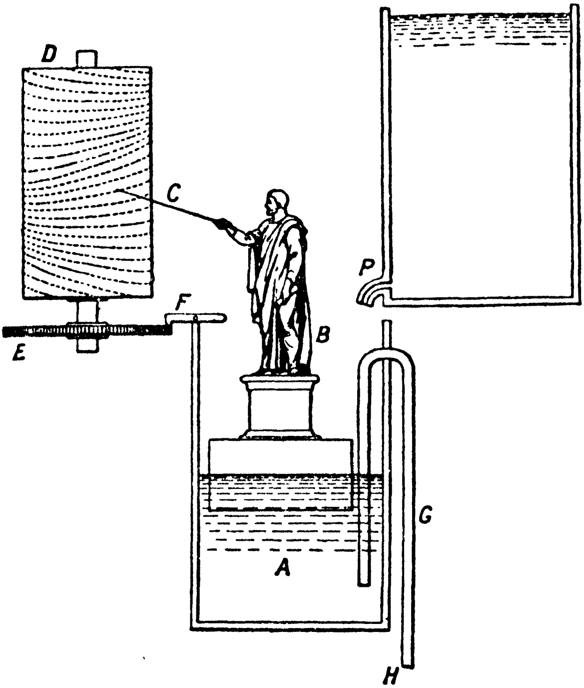
[1] See note at end of Chapter I.

known to the Chaldeans centuries before the particular form invented by Berosus came into use, and it is said that Anaximander (611–545 B.C.) introduced some of them into Greece. The clepsydra was a water-clock, one vessel being maintained full of water and just overflowing, the water thus dripping at a uniform rate through a small opening at the bottom into another vessel. A floating figure in the latter vessel gradually rose as the water dripped in, and an index pointed to the time, which was indicated by lines on a scale (see Fig. 2). The Chaldeans divided the day into twenty-four hours and made accurate observations of the rising and setting of the heavenly bodies. It is even suggested that they predicted the return of comets. But this is certainly apocryphal, unless the predictions were restricted to those periodic comets which had been observed to return repeatedly; in which case the predictions were not based on any dynamical principles, but merely on observation.

The Chaldean observations of eclipses have been very useful in recent times for determining the amount of retardation of the earth's rotation, due to tidal friction. The late Dr. J. K. Fotheringham made a careful examination of the old records of eclipses from Greek and Chaldean sources, and a comparison between the times of eclipses and the times at which they should have occurred, if the earth's rate of rotation were uniform, provides conclusive evidence that the earth is now rotating more slowly than it did in the past. Although the increase in the length of the day is extremely minute, in the course of many centuries the errors accumulate, and are appreciable. The lengthening of the day is due to tidal friction, which is most effective in some of the shallow seas and bays.

Ur of the Chaldees attained its greatest pre-eminence among the cities of Mesopotamia about 2300 B.C., or perhaps a little later. The principal building in the city was the Ziggurat, the site of which has been identified, and cylinders containing inscriptions of Nabonidus give the history of the building. The temple with which the Ziggurat is associated was dedicated to Nannar, the moon-god. As this book is not concerned with ancient history, it is impossible to introduce historical matter which might, in

other circumstances, be of direct interest. One event may, however, be mentioned. The remains of some tablets now in




[From *Time and Clocks*, by H. H. Cunynghame (*by permission of Constable & Co., Ltd.*).

FIG. 2.—CLEPSYDRA, OR WATER-CLOCK.

The vessel on the right is maintained full and overflowing, and water drops slowly from it through the opening *P* into the vessel *A*. As the water-level rises in *A*, the floating figure *B* rises and the index *C* moves over the scale on the drum *D*. When the float reaches its highest point it moves the wheel *E* through one tooth by means of the pawl *F*, and the syphon *G* then empties the vessel *A*, and a new day begins. The wheel *E* has 365 teeth, so that the drum turns round once in a year. The lines on the drum give readings in temporary or seasonal hours: in summer, twelve long daylight hours and twelve short night hours; in winter, the reverse.

the British Museum give an account of the conquest of Elam by Ashur-bani-pal, King of Assyria. It is recorded that in the past a king of Elam, named Kudur-Nankhundi, had carried away an

image of the goddess Nannar, and that Ashur-bani-pal had recovered it. Perhaps, in those days, it was considered a great triumph to capture the god of another country, and in this connection the story of the capture of the ark of God by the Philistines, recorded in 1 Samuel v, is interesting. It is stated that the Philistines placed the ark in the house of Dagon, and that Dagon was found prostrate in the morning, having fallen before the ark. Various afflictions overtook the people of Ashdod, where the temple of Dagon stood, and finally, after consulting the priests and diviners, it was decided to return the ark with presents to the Israelites.

The union of the Sumerians, the early inhabitants of Mesopotamia, with the Semites who predominated in Northern Babylonia, created the Babylonians, with whom we shall deal chiefly in the remainder of this chapter. From the library of Ashur-bani-pal, previously referred to, a great store of astronomical and astrological lore has been collected, and it provides us with many interesting facts in connection with the ancient astronomy of Babylonia.

About 2550 B.C. Sargon of Akkad, a Semite, conquered most of the country and probably territory beyond it, and during his reign the sun-god was given the primary place in religious devotion. Sargon is represented as carrying a saw, with which he cut decisions, and rays of the sun are shown emanating from his shoulders. Other astronomical bodies, and also natural objects and phenomena, were embodied in the Babylonian pantheon. The well-known signs of the zodiac, except those of Cancer and Sagittarius, can be identified as known to the Babylonians. Among their gods, in addition to the sun-god, were Nabu (Mercury), the god of science and learning; Ishtar (Venus), corresponding to the goddess of love and beauty of the Greeks at a later period; and Nergal (Mars), the god of war and hunting. Shamash was once the sun, and Marduk was Jupiter; but at a later period the name Marduk came to be applied to the sun. Saturn was known as Ninurta.

A very elaborate system of astro-theology characterized the Babylonian religion, and astronomy, like other sciences, developed

under the control of the priests. Within the precincts of the temple stood the observatory, and a religious character was given to astronomical observations on which the compilation of the calendar depended. It must not be assumed that the astro-theology of the Babylonians went back to very ancient times; it seems much more probable that, when the official religion had crystallized into shape, and a map of the heavens had been compiled, the official gods were then identified with some of the heavenly bodies. This does not imply that astro-theology exercised no influence on the religious development of Babylonia. Just as the rivers and streams were worshipped—largely because the people knew what they owed to them—so, too, the stars were worshipped; and hence astro-theology had a background in the faith of the people.

The esteem in which the astrologers were held is shown in the Book of Daniel, which tells us how Daniel interpreted the dream of Nebuchadnezzar when the magicians, the enchanters, the Chaldeans, and the soothsayers had failed. Although the Book of Daniel was almost certainly written about 167 B.C., during the persecution of Antiochus Epiphanes, the events recorded in it refer to a period about 600 B.C., and there is no reason for doubting the accuracy of the delineation of the influence and power of the astrologers at the Royal Court. It was almost impossible to separate astrology from important State functions, and we may safely infer that it had a very important influence among the wealthier classes, who could afford to pay for the information supplied to them. It is doubtful, however, whether all classes were able to indulge extensively in this luxury, and perhaps its devotees were limited to people of position and rank.

Something will now be said regarding the religious ideas of the Babylonians, a few of which were incorporated, with certain modifications, into the religion of the Hebrews, and transmitted by them to the Christian faith. Their views of cosmogony will be included in the survey.

Reference has already been made to a number of Babylonian gods, but the list is far from complete. Although there were many gods who presided over various matters in human life, in

the phenomena of nature, and even in the invisible world, the Babylonians had not the thousands of gods that the Egyptians possessed. A king might give the primary place to some particular god, but this deity was not regarded as the only one. He was merely one of many, though by some he might be regarded as supreme. The gods were divided into classes, which included the great gods and the primeval gods, the latter opposing mankind and the former assisting them. Among the primeval gods, Tiamat played an important part in the story of creation.

The story of creation was intended to glorify Bel-Merodach, by describing his contest with Tiamat, the dragon of chaos. First of all, an account is given of the creation of the world out of the primeval deep and of the birth of the gods of light; then comes the story of the struggle of the gods of light against the powers of darkness. In this war Merodach gained the victory and clove Tiamat into two pieces, forming the heaven out of one half of the body, and the earth out of the other. After disposing of Tiamat, he then arranged the stars in order, as well as the sun and moon, and gave them laws, which they were not to transgress. Plants and animals were then created, and finally man. This account of creation was written many centuries after Ea, the water-god, was regarded as the creator, having fashioned man out of clay.

In early Babylonian history the moon, not the sun, was used to measure time, and the first calendar was a lunar one. The early Sumerians called the moon-god "En-Zu," which means the lord of knowledge, because it was through him that they learned to regulate the year and also the festivals of the gods. It does not appear, however, that the moon-god was included among the three chief gods throughout all Babylonia, and it was only at Ur and Harran that he enjoyed this honour. The sun-god was born of the moon, and the sun seemed to rise from the darkness, over which the moon held dominion—an inversion of our conception of the order of importance of the two bodies. As the day was thus begotten by the night, it was reckoned from evening to evening, and this explains the order indicated in the first chapter of Genesis—"the evening and the morning were the

first day." This was simply a perpetuation of the older system of Babylonian astronomy; in later Babylonian history we find that the day begins at midnight.

The following hymn addressed to the moon-god, known at Ur by the name Nannar, shows the veneration in which he was held by the worshipper:—

> Father, long suffering and full of forgiveness, whose hand upholds the life of all mankind,
>
> Lord, thy divinity, like the far-off heaven, fills the wide sea with fear . . .
>
> First-born, omnipotent, whose heart is immensity, and there is none who shall discern it . . .
>
> Lord, the ordainer of the laws of heaven and earth, whose command may not be broken . . .
>
> In heaven, who is supreme? Thou alone, thou art supreme!
>
> On earth, who is supreme? Thou alone, thou art supreme!
>
> As for thee, thy will is made known in heaven, and the angels bow their faces.
>
> As for thee, thy will is made known on earth, and the spirits below kiss the ground.
>
> As for thee, thy will is blown on high like the wind; the stall and the fold are quickened.
>
> As for thee, thy will is done on the earth, and the herb grows green.

This hymn, which figured in the ritual of the great temple at Ur, shows that (in Ur at least) Nannar was no mere local god, but was supreme. One remarkable feature of the invocation is its monotheistic tone throughout—in strong contrast to the polytheism which characterizes the solar hymns.

The myth concerning the descent of Ishtar into Hades to seek her husband, Tammuz, to bring him back to earth, gives us an idea of the Babylonian conception of the conditions of the spirits in the other world. We are told that " dust is their bread, and

their food mud; they see no light, they dwell in darkness." The words of Job reflect the same conception when he speaks of the land to which he will some day depart, to return no more: "Are not my days few? Cease, then, and let me alone, that I may take comfort a little, before I go whence I shall not return, even to the land of darkness and of the shadow of death; a land of thick darkness, as darkness itself; a land of the shadow of death, without any order, and where the light is as darkness" (Job x, 20–22). Even kings were not exempted from this land of darkness and gloom, as we can infer from the ironical description of the fall of the Babylonian monarch given in the Book of the Prophet Isaiah by one who was conversant with the views of the Babylonians on the future life (Isaiah xiv, 9 *et seq.*). Although it is highly probable that Isaiah himself did not write this passage, the author was familiar with the current views at the time, and there seemed to be no happier place for kings, in the land of gloom, than for their humblest subjects.

It is remarkable that the Babylonian religion did not teach anything about rewards and punishments in the future life; the same fate in the land of darkness awaited everyone, whatever his conduct on earth. In this respect the Babylonian conception differed essentially from the Egyptian systems, as we shall see later. In this world a man was rewarded for his piety or punished for his evil-doing; consequently the religious thoughts of the Babylonians were centred upon life on earth. In the earlier days it was believed that the correct fulfilment of the rites and ceremonies of religion brought favours from the gods, and their non-fulfilment would bring misfortune. In the course of centuries the Babylonians were more impressed with a sense of sin—at first merely of a ritual or ceremonial nature—but later the gods were believed to be moral agents, hating wrong and loving righteousness. They were believed even to render assistance to the creatures whom they had made, but they were also prepared to chastise them when they offended. The Babylonian conception of the after-life, however, did not undergo any great change, and a common lot awaited all beyond death's gloomy portals.

In spite of the fact that no reward was expected in the other

world, the Babylonians paid great attention to their domestic and civic responsibilities. The code of Hammurabi, who lived more than two thousand years before the Christian era, is a monument of legislative skill and makes provision for nearly every contingency that might be expected to arise among the members of a community.

The literary epics of ancient Babylonia were numerous, and fragments of many of them have been saved for us. Generally speaking, they belong to the age of national revival which began with Hammurabi and continued for some centuries after his death. The *Epic of Gilgames*, the author of which was Sin-liqi-unnini, marks the final stage in the literary development of the tales which compose it, and the eleventh book, which contains the story of the Deluge, represents a combination of different versions current in Babylonia. Even in the age of Hammurabi, the author of the story makes the flood a punishment inflicted on the human family for its misdeeds. Tamzi is, however, rescued by Ea on account of his piety. While the misdeeds of mankind were mostly involuntary violations of the ceremonial law, there is nevertheless a profound sense of guilt associated with them—a marked contrast to what is found in Egypt, as will appear later. The story of the Deluge, which has many points of resemblance with the Biblical account, is worth recording very briefly.

Tamzi, the son of Ubara-Tutu, is the hero of the deluge story, and is warned by Ea of the coming catastrophe. He orders Tamzi to build a ship and to put into it his household and his wealth and also the beasts of the field. The story is related by Tamzi himself to the solar hero Izdubar. He tells how he coated the ship within and without with bitumen, entrusting all to a seaman, and how the sun-god and other gods—though Ea is not mentioned among them—sent rain, the rain-flood destroying all life from the face of the earth. On the seventh day there was a calm, and the ship stranded on the mountain, Nizir. After seven days more had elapsed, Tamzi released a dove and then a swallow, both of which returned; and later he released a raven, which did not return. After this, he left the ship and made a libation. Ea intercedes with Bel to refrain from causing a second deluge, and

subsequently Tamzi and his wife, and the people with them, were carried away to be like gods.

Berosus, a Chaldean priest and historian who lived in the time of Alexander the Great, tells a slightly different story of the Deluge. The god Kronos warns Xisuthrus, tenth king of Babylon, in a dream about the coming deluge, and Xisuthrus takes with him, in the vessel, not only the steersman, but also his near friends. The freeing of the three birds is mentioned and also the grounding of the ship on a mountain, but its name is not given. Xisuthrus erected an altar and sacrificed, after which both he and his companions disappeared. The cause of the deluge is not stated, but it can be inferred from the special commendation of Xisuthrus for his piety. It is thought by some that the translation of the survivors to the paradise beyond the grave is added because they had learned the secret counsels of the gods, and for this reason the gift of immortality should be conferred on them. In the myth of Adapa, the first man, who was created by Ea, we are told that when he reached the gate of heaven, and Anu knew that he had beheld the secrets of heaven and earth, he ordered the food and water of life to be offered to him. Adapa, in obedience to the instructions of Ea, refused the food of immortality, and man remained mortal. Never again had he the opportunity to eat of the tree of life.

There is a similarity between some of these stories and those in the Book of Genesis. When Adam and Eve disobeyed the divine command, and ate of the tree of the knowledge of good and evil, we are told that the Lord God, seeing that man was become like one of the gods, to know good and evil, drove him out of the garden lest he should eat of the tree of life and become immortal. In Genesis v, 24, it is related of Enoch that he walked with God, "and he was not; for God took him." This may have some reference to the same idea—that those who became too intimate with the gods should not be allowed to live with mankind, probably because they might divulge certain secrets. Hence the translation of Enoch so that he did not see death (Hebrews xi, 5). The connection between a number of Babylonian legends and those related in the Hebrew sacred books will be dealt with when we

come to consider Hebrew astronomy. At this point it may not be inopportune to show the remarkable connection between the names used by the Babylonians, for the months of the year, and those used by the Hebrews :—

| Babylonian Name. | | Hebrew Name. | |
|---|---|---|---|
| Nisannu | Tashritum | Nisan | Tisri |
| Aiaru | Arahsamana | Jyar | Hesvan |
| Simanu | Kislimu | Sivan | Chisleu |
| Du'usu | Tebitum | Tammuz | Thebeth |
| Abu | Shabat | Ab or Abib | Shebat |
| Ululu | Addaru | Elul | Adar |

## CHAPTER III

# EGYPTIAN ASTRONOMY

THE priests of Thebes alleged that they originated exact astronomical observations, and they attributed their success partly to the clearness of their atmosphere. It may be conceded that the Egyptian climate was ideal for observing the heavenly bodies, and that stars could be seen clearly even when they were practically on the horizon. The priests in Egypt formed a distinct caste, enjoying legal privileges and a high social position, and undoubtedly they had much leisure for the study of astronomy. As companions of the king, and immune from taxation, they had few or none of the mundane cares and responsibilities which many of the Egyptians had, but it is questionable whether they made the best use of their opportunities. They were the depositaries of the national knowledge; but they carefully concealed it from the people by clouding it in allegories and legends, and it is certain that they very much exaggerated their own knowledge. It is now admitted that the efforts of the Egyptian priests were useless to the scientific school of Alexandria; not once does Ptolemy mention any observation made by a native Egyptian. Although they observed eclipses of the sun, they did not record them; and none of their eclipse observations can be utilized to-day, as can those of the Babylonians and Greeks, to determine the changes in the earth's rate of rotation. Diodorus, who visited Egypt in 60 B.C., believed that they predicted the appearances of comets, but we need not take this statement seriously.

On the authority of Herodotus, the year, with its division into twelve months, was the invention of the Egyptians. According to his report, each month consisted of thirty days, and five complementary days were added to make the Egyptian year consist of 365 days.

Assuming that Herodotus was correct in his statement, the Egyptian year, in his time, was not so accurate as the year of the Greek octaëteric cycle, which implied a knowledge of the odd

quarter of a day (see p. 50). Aristotle refers, for a proof of the positions of the planets beyond the sun and moon, to ancient observations by the Egyptians and Babylonians, which had become known to the Greeks. We may well believe that at the beginning of the fourth century before Christ the Egyptians had accumulated a larger stock of astronomical facts than had the Greeks. It is difficult to assess the value of such an accumulation, and a statement in Aristotle's *Meteorologics* about Egyptian observations causes us to doubt the reliability of some of their information. In the work mentioned, Aristotle refers to the Egyptians as attesting the fact that some of the fixed stars acquire tails like comets. It is worth noticing that Aristotle does not refer to any astronomical treatises produced by Egyptian astronomers; nor does he mention any observations by them communicated to the Greeks in writing.

The Great Pyramid at Ghizeh, in the neighbourhood of Cairo, shows that the Egyptians, by some means beyond our comprehension, attained proficiency in the mechanical arts. They were able to quarry rocks of the hardest material, to transport the finished stone to great distances, and to raise huge blocks—a feat that would puzzle some of our modern engineers, with all their appliances. Not only so, but they were able to polish granite and to carve on it with the greatest ease, some enormous statues being covered with hieroglyphics of fine finish. The stones of the Great Pyramid, built by the directions of Cheops, were quarried in the Arabian mountains, and none of these stones is less than 30 feet in length. The time taken to complete the pyramid was about 20 years, and forced labour was employed, about 100,000 people working in relays of three months.

The Great Pyramid covers more than 13 acres, and is 480 feet high—about 100 feet higher than St. Paul's Cathedral. Its sides face the cardinal points, as is the case with most of the other pyramids, but it differs in certain details from all the others. This great edifice contains 85 million cubic feet of stone, and its erection to-day, at the current rate of wages, would cost many millions of pounds sterling. It is amazing to think that each pyramid was built as a tomb to enclose a mummy. A second

pyramid, near the first, was built by the successor of Cheops, and the inscriptions on the stones give his name as Shafra. A number of other pyramids are known and are smaller than those just referred to.

Much trouble has been taken to discover the principles on which the Great Pyramid was erected, and unfortunately a considerable amount of useless and misleading material on the subject has been published. Some of those who are interested in the architecture of the pyramids have read cryptic interpretations into the structure of the Great Pyramid, and it is supposed to foretell many of the chief events in the world's history. Among these may be noticed the Exodus of the Israelites from Egypt, the duration of Christ's life on earth, the date of the Reformation, of the 1913 Balkan War, of the Great World War in 1914–18, etc. It seems that it also supplies us with the standards of weights and measures; the number of days in the three years, solar, sidereal, and anomalistic; the value of $\pi$ (the ratio of the circumference of a circle to its diameter), and many other facts as well. It would be a waste of time to discuss such puerilities as these, but we shall proceed to examine the architecture of the Great Pyramid to see if it indicates much astronomical knowledge.

The inclined gallery in the Great Pyramid is directed to a point $3° 42'$ below the pole of the heavens, and it is certain that it was directed to a star which was nearest to the pole at the time of its erection. This star was Thuban, or $\alpha$ Draconis, and a simple calculation shows that it was at a distance of $3° 42'$ from the pole about 3440 B.C. and 2160 B.C. On historical grounds the editors of the *Cambridge Ancient History* assign the date 3100 B.C.; but some believe that the Great Pyramid was built at the earlier date. Beyond this particular feature in the design there does not appear to be any important astronomical significance in the edifice.

Some of the Egyptian temples were clearly designed to point towards the sun at rising or setting on certain occasions; these were either the solstices or the equinoxes. The temple of Amon-Ra, at Karnak, although now in ruins, was once a very impressive structure, and originally there were two temples on

the site. The chief of these looked towards sunset at the summer solstice, and the other towards sunrise at the winter solstice. In *The Dawn of Astronomy*, by Sir Norman Lockyer, it is pointed out that the whole construction of this temple had a certain object—to confine the light which fell on its front into a narrow beam and to carry it to the sanctuary at the other end. When the sun set at the summer solstice each year, the light passed, without any interference, along the whole length of the temple, and impinged on the sanctuary wall, illuminating the sanctuary in a most resplendent fashion.

Although the azimuth [1] of the sun at sunset, at the summer solstice, is now about a degree south of the azimuth of the axis of the temple, this discrepancy can be explained by secular changes in the azimuth of the sun at sunrise and sunset, caused by the alteration in the obliquity of the ecliptic. When the temple was built, the sun shone precisely on the sanctuary at the solstice, but in the course of centuries it would fail to do so. The erection of a temple designed to allow the beam of sunlight to fall on the place desired does not necessarily indicate advanced astronomical knowledge; it was merely a case of observing the position of the sun at sunset during the summer solstices. It is probable that Stonehenge was originally erected to mark the position of sunrise on the longest day, although the axis of the structure no longer points exactly to the direction of sunrise at the summer solstice.

The Egyptians depended on the Nile to irrigate and fertilize a considerable portion of their country, and it was important to determine as accurately as possible the time at which the river would overflow its banks. It happened that this took place about the summer solstice, and it was left to the priests, with their astronomical knowledge, to predict when it was to be expected. The temples which had the solstitial orientation—that is, which

[1] For the present purpose we need only consider the azimuth of a body when it is on or close to the horizon. In these circumstances the azimuth of the body is its angular distance, measured along the horizon, from the north point. The azimuth of the sun when rising at the vernal or autumnal equinox is 90° east, and when setting it is 90° west, for all places on the earth's surface. In the latitude of Greenwich, at the summer solstice, the azimuth of the rising and setting sun is about 50° east and 50° west, respectively.

were oriented towards the rising or setting sun at the summer solstice—would supply the necessary information, the sun at the summer solstice shining on an image of the god in the sanctuary. It was thus possible for the priests to combine very important predictions with pious fraud. In the clear Egyptian atmosphere it often happened that the tip of the sun was able to cast a shadow a few seconds after it had appeared above the horizon, and hence at sunrise or sunset an image in the sanctuary could be illuminated, provided the temple was oriented accordingly.

A sun temple would serve its purpose for a very long time because the small changes in the obliquity of the ecliptic would make little difference to the azimuth of the rising or setting sun at the equinoxes. A star temple did not possess this advantage, on account of the phenomenon known as the precession of the equinoxes, and in the course of a few centuries it would fail in its object. The star temples were sometimes used to determine the times of the helical rising and setting of a star—a phenomenon about which something will now be said.

When we speak of the helical rising of a star we mean that it appears in the morning a little in advance of sunrise, and of course sets at twilight a little earlier than the sun. Throughout Egypt the sun was considered to be about 10° below the horizon when a star was stated to rise helically, but something would depend on the brightness of the star, and for faint stars it was necessary that the sun should be more than 10° below the horizon. In ancient times the priests had noticed that Sirius, the brightest star in the heavens, rose helically about the time of the summer solstice, and this day was chosen as the first day of their year, the name Thoth being applied to the first month. The light from a star was able to illuminate the sanctuary to a certain extent—not of course as much as the sun—and the Egyptians constructed their temples in such a way that all stray light was kept out of the sanctuary. It has been pointed out that they adopted a method almost similar to that used in modern telescopes, which have a series of diaphragms with inner diameters diminishing from object glass to eye-piece. The result of this arrangement is that all the light falling on the object glass also falls on the eye-piece,

no reflection occurring from the sides of the tube. By means of apertures in the pylons and separating walls of the temples, the same effect was produced, and light which shone on an image in the sanctuary could not be observed elsewhere by the worshippers. The construction of the temples shows a certain amount of ingenuity on the part of the priests, who obviously wanted to keep important information within their own particular circle and to conceal it from the people.

Star temples were also built to observe the rising or setting of certain stars, irrespective of the helical rising; but in about 300 years the precession of the equinoxes would render them unsuitable for this purpose, as the star at rising or setting would not shine down the axis of the temple. This explains why two or more temples with different orientations are sometimes found close together, the later ones having been constructed when the starlight no longer served its original purpose in the earlier temple. An instance of this is found in the temples at Medînet-Habû, which according to Sir Norman Lockyer, were built to observe *a* Columbae, the dates of building being approximately, 2525, 1250, and 900 B.C.

The temple at Luxor was first built, according to some authorities, about 4900 B.C., and many centuries later an addition was made end on. As the star was then somewhat out of its original line, the axis of the temple was bent to deal with the new situation.

Some light is thrown on the condition of Egyptian astronomy by the writings of Manetho, an Egyptian priest who lived in the third century B.C., and was the keeper of the sacred archives of the temple of Heliopolis. He tries to prove that the Egyptians were conversant with every branch of science; but it is doubtful if he has succeeded in establishing his point, and an example of the astrological teaching at that period is illuminating. It appears that when Mercury strikes, with his rays, the light from Venus, so that they both illuminate the zodiac, children who are born at the time will become geometricians, mathematicians, astronomers, sacrificers, magi, diviners, and augurs. They will even be able to predict the future by means of water, and perform other signs and wonders. The astronomical portion proper, in the second

book, fixes the number of the circles of the sphere as nine. It distinguishes between those which we see only with the spiritual eyès, such as the meridian, the horizon, the Arctic circle, etc., and those which are actually visible, such as the Milky Way. Obviously Egyptian astronomy was not in a very advanced stage in the days of Manetho.

The Egyptians, in addition to having many earth-gods and others of a general character, associated some of the heavenly bodies with gods. Tum, the sun-god, originated from the ocean and begat four children: Shu and Tefnut, representing the atmosphere; Geb, the earth; and Nut, the heavens. Geb and Nut were responsible for producing four more gods; these were Osiris, Isis, Set, and Nephthys. This group of nine gods, a trio of trios, constituted a Great Company which was the "ennead" (Greek nine) of the ennea gods. Each temple had an ennead, which varied according to the god in whose honour it had been erected.

The Egyptians believed that the condition of individuals in the future life was largely dependent on their manner of life on earth, and the account of the judgment showed how carefully men's actions were investigated. The immaterial heart, known as the "Ka," made its way to the regions of the other world until it reached the place known as the Abode of Hearts. It met the dead man to whom it belonged, and in the judgment hall it accused him of all his evil words and thoughts, or testified to his good words and thoughts. The heart was not the cause of a man's words and thoughts—being essentially pure and divine—and it was an unwilling witness of his sins. Finally, the heart was weighed in the balance against the image of Truth, and if the scales turned in favour of the dead man it was able to rejoin its former body and live with it for ever in the islands of the Blest.

The *Book of the Dead* is largely taken up with magical words, formulæ, and actions which are necessary to enable the dead person to go through the various tests imposed before he can pass many obstacles which might prevent him obtaining entrance into the Hall of Osiris. It is true there was an insistence on righteousness; but the real value of righteousness was lost in the

magical additions, and no doubt the priests found it lucrative to supply the necessary portions of the *Book of the Dead* to be buried with the deceased. Those who could not pass the specified tests were subjected to a terrible punishment: their heads were cut off by the headsman of Osiris; their bodies were dismembered and then destroyed in pits of fire. Perhaps this was not such a terrible punishment after all, because complete annihilation took place, so there was no fear of everlasting torment.

A remarkable political upheaval took place in Egypt when a change was introduced involving the worship of the sun-god as the one and only god. Amenhotep IV, who reigned from 1380 to 1362 B.C., rejected the cult of Amon Ra, separating himself from the priests of Amon at Thebes and establishing his new capital at Tell-el-Amarna. He abandoned his former name and adopted the name Akh-en-Aten, or Ikhnaton, which means "The Blessed of the Disk." His "Hymn to the Sun-Disk," from which the following excerpt is made, shows that he was a strict monotheist:—

> Thou makest the seasons to preserve all that thou hast created—the winter to cool and the flood. Thou hast created the heavens afar, to go up unto them, that thou mayest see all that thou hast made. Thou art One, but thou ridest in the form as the living sun, appearing, shining, giving, and returning. . . . Thou art in my heart, and none knoweth thee as doth thy son Akhenaten whom thou hast deigned to let comprehend thy thoughts and thy strength.

A king who devotes most of his attention to the exercises of religion is liable to forget the claims of the State, and unfortunately this occurred in the case of Akhenaten. During his reign the Egyptian empire in Palestine and Syria collapsed, and he made no attempt to maintain his authority in Asia. No military expedition was undertaken by him, and soon after his death the Asiatic empire was lost to Egypt. His new capital at Tell-el-Amarna, on the east banks of the Nile, was destroyed, the cult of Aten died out, the shrine of Marmachis which he had built at Thebes was pulled down, and the stones were rebuilt into the

temple of Amon. The priesthood of Amon was too strong for the new religion to make headway, though it was an advance towards monotheism. The Tell-el-Amarna tablets, 320 in number, the first of which was found in 1887, give a wonderful insight into the political history of the time and also into the character of the ascetic king, who has been described as "a pathological subject, hyper-nervous, and with an irritable brain that made him a genius, while at the same time his body degenerated. It is more than probable that he died mad."

Perhaps posterity will learn the lesson that high ideals without the power to back them up, by force if necessary, and genius devoid of practicability, are doomed to failure in a world in which superstition, stupidity, and selfishness are still powerful factors in human nature.

We may conclude from this short outline of astronomical knowledge among the Egyptians that we owe very little to them in this science, and that they have handed on to posterity practically nothing of astronomical value. In addition, it does not appear that astronomy had very much influence on the social life of the people on the whole, or that their religion was greatly influenced by the subject except in so far as they worshipped a number of gods which they associated with different heavenly bodies. The number of these, however, was small in comparison with that of other gods, and polytheism seems to have had a strong hold on the Egyptian mind. It must be admitted, however, that it is difficult after a lapse of thousands of years, to judge of people's real religious views by fragmentary records or by pictorial delineations of their gods. What conception would a future race gain of the Christian religion from a heterogeneous collection of works in the English language? Even with access to definite Christian literature it is doubtful if a clear idea of Christian views would be attainable. If the scholars of this hypothetical race judged the Christian faith from paintings and statues which were supposed to represent forms and methods of worship, they might conclude that they were dealing with a polytheistic religion in which a woman and a child, a lamb, and even a dove, were worshipped.

## CHAPTER IV

# HINDU ASTRONOMY

The astronomy of the Indians forms a difficult problem, and, in spite of a considerable amount of research and discussion, the subject still remains involved in great uncertainty. Although we are in possession of many of the tables by means of which the Indians computed eclipses and planetary positions, it is not always possible to decide on the source from which such tables emanated, or even on the periods to which they are to be attributed. Some of the controversy on the subject is not free from acrimony, and distinguished scholars have been ranged on different sides, each side producing evidence in support of its own view. The controversy is concerned in particular with the question of the antiquity of the Hindu astronomical conceptions, which were first made known in Europe towards the end of the seventeenth century. It was more than a hundred years later that scholars had their attention drawn to certain portions of Vedic literature, which contain the real essence of Hindu astronomy.

It would be unprofitable to deal with these controversies on the antiquity or otherwise of Hindu astronomy; an outline of the most probable view will be sufficient. It should be added, however, that there is no implication that this is necessarily the last word on the subject. Future research may modify some of the views accepted at present.

The earliest sacred works of the Hindus are the *Vedas*, which contain a number of interesting astronomical references, and there are also valuable astronomical records in other works, such as the *Brahamanas*, *Upanishads*, *Sutras*, etc. The period of the Vedic collections is very doubtful; some authorities estimate that it was about 1200–1000 B.C., while others believe that it was much earlier. As sacrificial ritual occupied a very important place in early stages of Hindu history, the prevalence of crude astronomical notions is not surprising, because sacrificial rites are usually associated with seasonal changes or certain astro-

nomical phenomena. A passage in an early astronomical textbook says: "Since the *Vedas* teach the aim of sacrifice and sacrifices follow the order of time, therefore he who knows astronomy—that is, the science of time order—knows the sacrificial rites." Unfortunately the astronomical statements in the *Vedas* are sometimes very vague, and in consequence much speculation on their meaning has been inevitable. In the *Rig Veda* there are many beautiful hymns devoted to celestial phenomena, and these hymns are chiefly concerned with the attributes and praise of a number of divinities associated with heavenly bodies. The sun is the source of light, measuring day and night and driving away the stars like thieves, while his chariot has usually seven horses—five or six or even a thousand are sometimes attributed. Occasionally he is overspread with darkness by Svarbhānu, but this darkness is dissipated by Atri and by prayer. The moon, which is continually born again, orders the seasons, though playing a part subordinate to the sun. In spite of this, Soma (afterwards a moon-god) is of supreme importance.

It is contended by some that the Vedic seers had no knowledge of the planets, as there is no definite reference to them in the Vedic writings. The argument from silence, however, cannot be considered conclusive; the mention of the numbers "five" or "seven" [1] suggests at least a knowledge of their existence. The following passages may serve to show the possibility of this knowledge, and many others could be quoted:—

> May the five bulls who abide in the centre of the expanded heavens, having together conveyed my prayers quickly to the gods, return.
>
> Seven sages with five ministering priests attend the station that is prepared for the rapid.

The *Mhabharatas* mentions the planets by name, and the *Ramayana* refers to individual planets; but these works, while embodying some ancient astronomical tradition, contain a considerable amount that does not belong to the earlier period. As

[1] Seven includes the usual five planets (see p. 96) and also the sun and moon.

the later limits of portions of the *Mhabharatas* have been assigned to about A.D. 400, the fact that the planets are mentioned in the works referred to does not necessarily prove that they were known to the Vedic seers.

Very few constellations are mentioned in the *Rig Veda*, but it is believed that the seven Rishis referred to in one passage relates to the Great Bear, and it is probable that references in other portions are to Sirius and Orion. The *Atharva Vega* mentions eclipses and introduces Rahu, the demon of eclipses, while Soma and Rudra remove eclipses. It also refers to a thirteenth month of 30 days, and it is possible that this implies a five-years' cycle, each year containing 360 days, so that five years and the thirteenth month would contain 1,830 days, an average of 366 days for a year. Even the *Brahmanas*, which were probably written between 800 B.C. and 600 B.C., add very little of astronomical value, and the *Upanishads*, about 600 B.C., have a probable reference to the pole star which has been identified with $\alpha$ Draconis, from which the date 2780 B.C. has been deduced.

Regarding the difficulties attending the question of the dates of Hindu works, reference may be made to the *Sūrya Siddhanta*, supposed by some to be one of the earliest of the astronomical works of the Hindus. It consists of short aphorisms which form a set of rules for calculating the positions of the heavenly bodies, and is written in Sanskrit. It shows that the difference between the sidereal and terrestrial day was known, and it discusses the length of the solar year and the sidereal year, the latter being 365 days 6 hours 12 minutes 36 seconds. It gives the apogees and the nodes for the five planets, and shows how to find the mean position of a planet at any time, referred to Lanka, the prime meridian for India. The diameter of the earth is given as 1,600 *yojanas* (a *yojana* is 4·9 miles), and hence the earth's diameter was known to be 7,840 miles; and even the moon's horizontal parallax and distance from the earth are given, the latter being 51,566 *yojanas*, or about 253,000 miles—a remarkably good figure. Many other important astronomical facts are mentioned in this work, for which immense antiquity is claimed; but, unfortunately for this claim, and for those who still quote the

work to support the view that the ancient Hindus possessed exact astronomical knowledge, it is almost certain that it is comparatively modern. It is now believed that in its present form it dates from about A.D. 1000. The astronomical elements in the text imply a date 3102 B.C., when all the planets were supposed to be in conjunction, and one would naturally believe that this date corresponded to the actual observations of Hindu astronomers at that time. It has been shown, however, that there was nothing even approaching a general conjunction at that period, and evidence from different sources points, as stated, to a much later date for the work.

It is now generally accepted that from A.D. 400 Hindu astronomical teaching is dominated by the Greek system of astronomy. This is proved by the statements of early Hindu writers and also by the use of Greek technical terms in Hindu works. Varāha Mihira, who died about A.D. 587, refers to Greek astronomers in his *Brihat Samhita*, which is an astrological treatise, and other writers about the same period also refer to the Greek astronomers. As Greek astronomy will be dealt with in the next chapter, this is not the appropriate place to consider Hindu astronomy after it came under Greek influence. It may be pointed out, however, that about the middle of the fifth century A.D. the Hindus welcomed the teaching of the Greeks, which Europe had despised and rejected, thus ushering in the period of the "dark ages." If, as tradition says, the Arabs first received their knowledge of scientific astronomy from India, it is just possible that the Arabs also may have been induced to acquire knowledge from the Greeks. It is remarkable that centuries later Europe was able to receive from the Arabs the very teaching that it had previously rejected.

In the early Hindu writings, while some passages seem to approve of astrology, others condemn it. Baudhāyana enumerates the offences which make a man impure, and among these is gaining one's livelihood by astrology. The laws of Manu warn people that he who subsists by astrology should be avoided. The early Buddhist texts condemn the practice of astrology, and no doubt the Brahmans were influenced by these prohibitions,

but in later times Buddhism assimilated certain astrological notions. The *Atharva Veda* gives a list of twenty-seven asterisms or *nakshatras* (each *nakshatra* was a small cluster of stars which lay in the path of the moon), and this list seems to have an astrological significance. There is no planetary astrology suggested here, and many centuries elapsed before the planets were introduced into the earlier astronomical magic. This suggests, as previously mentioned, that the planets were not known to the early Hindu astronomers. The great Indian work on astrology is Varāha Mihira's *Brihaj-Jataka*, which *inter alia* deals with the most auspicious positions of the planets, the planetary domiciles, the influence of each house, the values of the planets, the quarters ruled by them, as well as their sex and elements, their aspects, and their friendly or unfriendly relations with one another, etc. A great portion of the work applies these notions to problems of birth, death, vocation, and so on, and some chapters deal with configurations and lost horoscopes.

In Vedic times there was a sun-god group, but in the *Rig Veda* only one of them—Sūrya—is definitely astronomical. He is the source of light, the day-measurer, and the dispeller of darkness. Savitri was the vivifier, and Mitra had some resemblance to Mithra, a god of light. Pūshan is sometimes said to be a sun-god, and in later times this name is used as the name for the sun. In post-Vedic times Vishnu became the first of the Ādityas, a group of gods, though he holds a subordinate position in the *Rig Veda*. Soma is the name of the moon in the *Atharva Veda*, but in more modern times the moon occupies a very subordinate position as a divinity. It is remarkable that, while the moon is important in regulating religious practices in India, a moon-god has no place in the Hindu pantheon.

In post-Vedic times there is a different conception of the celestial deities. Thus, in the *Brahmanas*, the Ādityas have been increased to twelve, and represent the twelve months of the year; and later the whole group became merged into one sun-god to which various titles were applied—Sūrya, Sāvitri, Mitra, Aryman, etc. The *Mahabharata* gives 108 names to the sun, and the *Jatakas* refer to the worship of the sun, while the *Puranas* (about

A.D. 400) relate solar myths and tell of a race of solar kings. There is evidence which dates from the early years of the Christian era that a solar cult existed in mediæval India, and a planetary cult in addition. It is thought that planetary worship may be a foreign importation, perhaps of Magian origin, and was influenced by Mithraic teaching and Manichæan practices.

Buddhist astronomy does not seem to have attained much perfection, if the knowledge of a Buddhist monk is to be taken as a criterion. The monk who lives in the forest must learn the positions of the *nakshatras* and must also know the cardinal points. At the close of the ordination service the seniority of the monk is determined by "measuring the shadow," and instructions are given in such matters as the length of the seasons and the division of the day. The earth is supposed to be a flat disc, 1,203,450 *yojanas* (about 6 million miles) in diameter, and in its centre is Mount Meru, identical with the North Pole and once considered the home of the gods, rising 84,000 *yojanas* above the surface of the earth. The sun, moon, and stars circle round it, shining in turn on the four continents round Mount Meru. The diameters of the sun and moon are stated, and, in English measure, are respectively 245 and 240 miles.

Sufficient has been said to show that we owe very little to Hindu astronomy so far as direct influence is concerned. It has been pointed out that indirectly we are indebted to the Hindus because they imparted certain astronomical information to the Arabs, who, in turn, passed it on to Europe, and that the Hindus received their astronomical knowledge from the Greeks. In the next chapter we shall deal with the astronomy of the Greeks.

## CHAPTER V

# GREEK ASTRONOMY

THE origin of astronomy in Greece, as in other early nations, lies outside the period of authentic history. In the poems of Homer and in the works of Hesiod there are some indications of astronomical knowledge, but these are often meagre and vague. In addition to mentioning the sun and moon, Homer alludes to the morning and evening stars, the Pleiades, Orion, the Great Bear, Sirius, and "the late setting Boötes," which refers to Arcturus. His cosmogony is very crude. Round the flat earth runs the River Oceanus, from which all other waters originate, the waters of Oceanus passing through subterranean channels and appearing again as sources of the smaller rivers. The vault of heaven—a hemispherical dome—lies over the flat earth, and underneath the earth is a vault, called Tartarus, symmetrical with the heaven. In the *Iliad* Tartarus is a dark underground prison with iron gates, and is as far below Hades as earth is below Heaven. We are told that Cronus and the Titans were overcome by Zeus and his brothers after a ten years' struggle, and were thrust down to Tartarus, where they were guarded by the Hundred-handers. In later times we find that Tartarus is the place of punishment of the wicked after death, and we read about Æneas, in his visit to the abode of the shades, coming to a place where the road divides, one branch leading to the prison-house of Tartarus.

Hesiod, who lived about nine centuries before the Christian era and about two centuries after Homer, makes use of celestial phenomena for determining the times and seasons of the year. He was aware that spring commenced with the late rising of Arcturus, which, in his day and place, would be about February 24 (Julian Calendar). He fixed the sowing-time at the beginning of winter by the setting of the Pleiades in the early twilight, or by the early setting of the Hyades or Orion. Although he was acquainted with the solstices, he does not refer to the equinoxes, but he may have known about them, as he speaks of the

days becoming shorter and the nights longer in the late summer.

The true foundations of Grecian science were laid by Thales, who formed a sect distinguished by the title of the "Ionian School." Thales was born at Miletus in 640 B.C. and became very eminent in nearly every field of human activity, but we shall

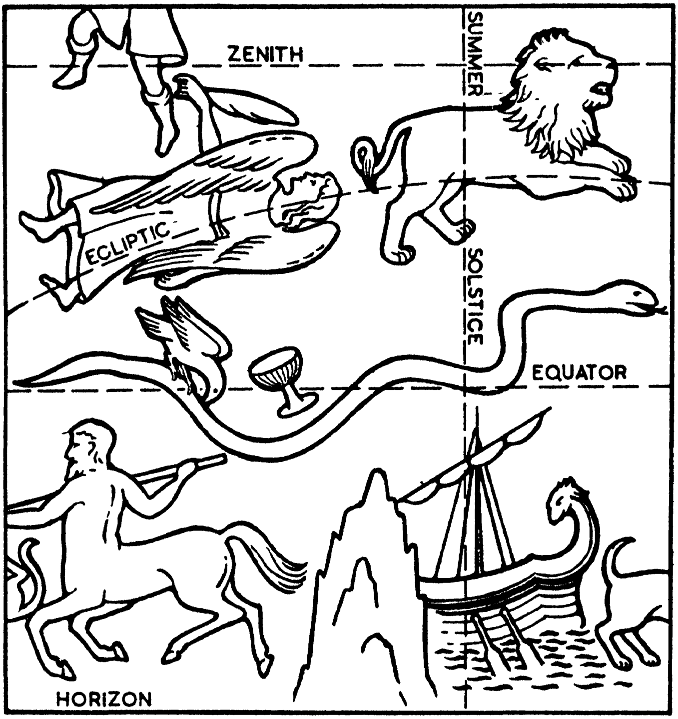



FIG. 3.—THE MIDNIGHT CONSTELLATIONS OF WINTER ABOUT 2700 B.C.

restrict our survey of his work to his astronomical teachings. He attained fame by predicting an eclipse of the sun which actually occurred during a battle between the Lydians and the Medes and was probably the eclipse of May 28 in the year 585 B.C. It is sometimes believed that he predicted the date, hour, and place when and where the eclipse would be visible, but this

view is quite incorrect. It is certain that he made use of the Chaldean Saros (see p. 10), and from this he concluded that a solar eclipse would take place in 585 B.C. The width of the shadow of the moon cast on the earth during a total eclipse is often under 70 miles, and it is possible for an eclipse to be visible in one place and quite invisible in another. It enhanced the reputation of Thales that this particular total eclipse should have been visible at the scene of the battle, but it is certain that he could not have predicted the places where totality occurred, and there is no evidence that he assigned the day or the month of the eclipse.[1]

Among some of the details of his astronomical knowledge reference may be made to his discovery of the inequality of the four astronomical seasons and of the length of the year as 365 days. It is possible, however, that he learned both these from the Egyptians. He knew that the ecliptic is cut obliquely by the equator, and wrote something about the solstice and the equinox, but it is difficult to say whether this was original or whether he learned it from the Egyptians. Callimachus informs us that he determined the positions of the stars in the Little Bear and advised the Greeks to follow the Phœnician practice of steering by this constellation (the Greek mariners used the Great Bear for navigational purposes). It is difficult to see how Thales, without any accurate instruments, could find the positions of the stars with sufficient precision to be of material assistance to navigators, and it is probable that he merely pointed out some of the more brilliant stars in the constellation which might be useful to sailors.

Thales and the philosophers of Miletus concentrated their attention on the problem of change. The world presented a spectacle of perpetual transformation, but what was the one thing which assumed so many shapes? Thales said it was water. Earth is merely the result of the condensation of water; air is produced from water by rarefaction, and when air is heated it becomes fire. Thales thought that the earth floated on water—a view which he probably owed to the Egyptians—but the same

[1] Some still doubt whether he ever predicted this eclipse.

idea is found in Babylonian cosmogony. It does not appear that Thales was in advance of the Egyptians and Babylonians so far as cosmogony is concerned.

The Greek genius for inquiry—the desire to know not only facts but the reasons for the facts—is displayed fully in Anaximander (611–545 B.C.). He taught that the one thing which took so many different shapes was not water but a boundless or infinite substance out of which are segregated the different substances with which we have to deal in the universe. Not only does the universe arise out of it; in the course of time the universe will all pass into it again. An infinite number of worlds exists at any one time, some coming into being, some at their prime, and some passing away. As a consequence of this eternal coming into being and passing out, it was necessary also to postulate eternal motion.

The portion of the infinite which separated off to form our world was first divided into two opposites, the hot and the cold, the former appearing as a sphere of flame which grew round the air about the earth as the bark round a tree. Afterwards the sphere was torn off and became enclosed in certain rings, thus forming the sun, moon, and stars. These rings were like circular hoops made of compressed air and enclosing fire inside them, but the fire did not appear to be continuous and could be seen at one place only. This occurred where there was a circular vent through which the fire shone; hence the appearance of the heavenly bodies. We need not enlarge on this crude conception, and shall proceed to examine some of the less extravagant views of Anaximander.

He believed that the earth was suspended freely and was a short cylinder in shape, remaining thus suspended because it was at an equal distance from all the other heavenly bodies. He taught that the sun was the same size as the earth and was about twenty-eight times the radius of the earth's plane face distant from the earth, the moon's distance being nineteen times this radius. He set up a gnomon in Sparta and marked on it the solstices, the times and seasons, and also the equinoxes. Posterity owes him a debt of gratitude for the invention of geo-

graphical charts, and although before his time the Egyptians had drawn maps, these were merely of particular districts.

Anaximenes (585–528 B.C.) identified the primitive substance with air and held that the earth was flat and supported by the air. He believed that fire is produced when moisture, rising from the earth, is rarefied, and the heavenly bodies are composed of this moisture which has risen high. He is said to have taught that the stars are fastened to a crystal sphere by studs, so stars that ride on the air must be planets. In the region of the stars there were bodies of an earthly nature which were carried round with

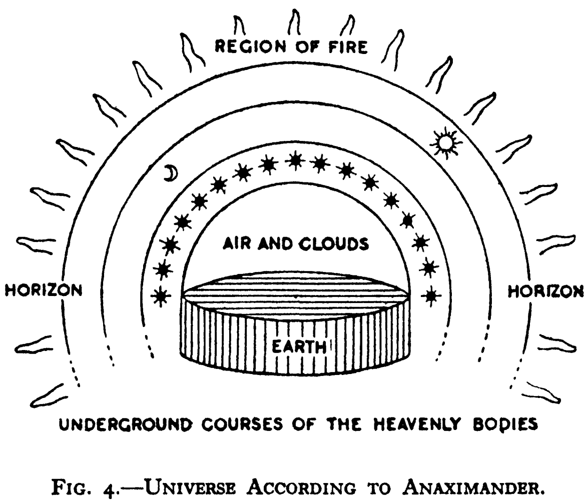



FIG. 4.—UNIVERSE ACCORDING TO ANAXIMANDER.

the stars, and it is thought that these were postulated to explain eclipses of the sun and moon.

Anaxagoras, the successor and disciple of Anaximenes, was born about 500 B.C. near Smyrna, and in later years moved to Athens, where he enjoyed the friendship of Pericles. If he held the opinions ascribed to him by Plutarch, we must assume that the Ionian school retrograded after the days of Thales. He is supposed to have taught that the sun is a red-hot stone, somewhat larger than Mount Peloponnesus, and the moon is of an earthy nature, with plains, mountains, and ravines (a very sane view);

that the heaven is a vault of stones, prevented from falling by the rapidity of its circular motion, and that the sun is prevented from advancing beyond the tropics by a dense atmosphere which forces him back on his path. It is probable, however, that these alleged views have been greatly distorted, and we must give him credit for the discovery that the moon does not shine by her own light, but receives it from the sun. He showed the reason for eclipses, and since he disregarded the superstitious notions of the age, ascribing to natural causes what was supposed to be due to the gods, he was charged with impiety and treason towards his country. Through the influence of Pericles the sentence of death passed on him was commuted to one of perpetual banishment.

Anaxagoras offered an extraordinary explanation of the Milky Way. He thought that, as the sun was so small, the shadow of the earth stretched for an infinite distance through space. As the light of the stars seen through the shadow is not overpowered by the sun, we are able to see more stars in that portion of the sky covered by the shadow than outside it.

The cosmogony of Anaxagoras had some resemblance to modern nebular hypotheses and shows that he possessed a speculative mind. He held that the formation of the world started with a vortex, the rotatory motion beginning at one point and then gradually spreading, wider and wider circles being included. Two great masses were separated by this rotation—the "æther" consisting of the hot, light, dry material, and the "air" consisting of the opposite categories. The æther or fire occupied the outer position and the air the inner, and from the latter were separated the clouds, water, earth, and stones. As a result of the circular motion the dense, the moist, the dark, the cold, and all the heaviest things, collected in the centre, and the earth was formed from these elements when they consolidated. Later on, in consequence of the violence of the whirling motion, the fiery æther on the outside tore stones away from the earth and kindled them into stars—a view which shows that Anaxagoras was aware of a centrifugal force overcoming the tendency towards agglomeration of the heaviest parts.

Whatever we may think of the cosmogony of Anaxagoras, we cannot but be impressed with his views on the plurality of worlds. A fragment of his writings shows us that he believed there were other earths which produced the necessary sustenance for inhabitants, and that each one of them had its sun and moon, just as with us. In some of his views he may be said to have anticipated modern astronomers by millennia.

A short reference may be made to the speculations of Leucippus and Democritus. Leucippus believed that the earth was a hemisphere, surrounded by a hemisphere of air, and outside this was

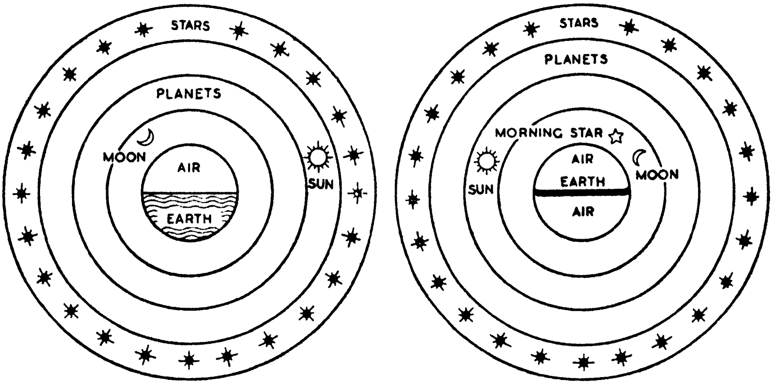



FIG. 5.

UNIVERSE OF LEUCIPPUS. UNIVERSE OF DEMOCRITUS.

a crystal sphere which held the moon; other spheres, beyond, holding the planets, the sun, and the stars. Democritus, a disciple of Leucippus, conceived of a disc-like earth which was slightly raised at the rim to hold its contents. This disc divided the sphere of air into two parts, so that the earth rested on air, which was also in the sky above. The underneath portion of the earth was believed to be uninhabited, possibly because of the difficulty of conceiving of people standing upside down. He placed the moon and the morning star together, and the other planets beyond the sun—an arrangement somewhat different from that of Leucippus.

The Ionian sect was occupied with propagating its views in Greece when Pythagoras (580–500 B.C.) founded a more celebrated sect in Italy. It is said that it was in Egypt that he acquired his knowledge of the obliquity of the ecliptic and of the identity of the morning and evening stars. He is credited with being the first to declare that the planets have a movement of their own, independent of, and in a contrary direction to, the daily rotation, but this knowledge was probably acquired from the Babylonians or the Egyptians. Many astronomical text-books repeat the story that he taught the motion of the earth around the sun, but this story is now discredited. For Pythagoras himself, though not for the later Pythagoreans, the earth was at rest at the centre of the universe, and the universe, like the earth, was spherical in shape.

An innovation in theoretical astronomy was made by the successors of Pythagoras in the Pythagorean school. This was the abandonment of the geocentric view and the reduction of the earth to a planet like the other planets—a view which was due to Philolaus. Philolaus appears to have spent a lot of time in useless speculation on the elementary nature of bodies, which was supposed to depend on their form; he assigned the tetrahedron to fire, the icosahedron to water, the cube to earth, etc. This conception not only showed a considerable amount of geometrical knowledge on the part of Philolaus, but it also encouraged the study of geometry, so that many important results were attained.

Philolaus was the first to propound the doctrine of the motion of the earth, and may be said to have anticipated Copernicus, but there is an essential difference between his views and the Copernican doctrine. According to Philolaus the earth and planets do not revolve round the sun, but revolve with the sun and moon round a central fire, which he calls the hearth of the universe, the house of Zeus, and the mother of the gods. In this central fire, which is invisible to us, is located the force which directs the activity of the universe. The five planets, the sun, moon, and earth, and also the sphere of the fixed stars, make up only nine bodies, and in accordance with his number theory he assumed a tenth, which he called the counter-earth. This accompanies

the earth, but revolves closer to the central fire than does the earth, and is invisible to us because the hemisphere on which we live is turned away from it and from the central fire. Such a system implied a rotation of the earth about an axis in the same time as it revolves round the central fire. The assumption of a counter-earth explained why eclipses of the moon occurred more frequently than solar eclipses, the former being due to the interposition of the earth as well as of the counter-earth and the bodies of an earthy nature assumed by Anaximenes. Day and night are due to the revolution of the earth round the central fire, the circuit being completed in 24 hours.

It is impossible in the limited space at our disposal to deal with the views of all the early Greek philosophers, and we must be content to consider a few of the early astronomers who stand out conspicuously in the history of astronomy.

Eudoxus (about 408–355 B.C.) had attended lectures by Plato and obtained a high reputation as an astronomer. The retrograde motions of the planets and also their stationary points had presented great difficulties to the Greek astronomers, and the first serious attempt to explain them and to furnish a mathematical basis for astronomy was made by Eudoxus. He supposed that each planet occupied a particular part of the heavens and that the path which it described was due to the combined motion of four spheres. The sun and moon had each three spheres, one revolving round an axis which passed through the poles of the earth, and caused the diurnal motion. A second sphere revolved round the pole of the ecliptic in a contrary direction, causing the annual and monthly revolutions; a third, revolving in a direction at right angles to the first, produced the changes of declination. By assigning a fourth sphere to each of the planets, stationary points and retrograde motion were explained. The combined motions of the third and fourth spheres caused a planet to describe a curve like an elongated figure-of-eight on the surface of the second sphere, and by combining the motion round this figure-of-eight with the motion in the circle of the zodiac a very good explanation was afforded of the planetary movements, including stationary points and retrograde motions. It was

quite a remarkable feat to invent the combinations of movements which led to such explanations, although it must be admitted that the system was very complicated. It became more complicated still when Callippus (about 370–300 B.C.) added two more spheres for the sun and moon, and one more for each of the planets, Mercury, Venus, and Mars. The two extra spheres for the sun were added to explain the unequal motion in his longitude.

Heraclides, surnamed Ponticus (about 388–315 B.C.), was said to have had his name changed to Pompicus by the wits in Athens, because of his eagerness to maintain state in the city. Many stories are told about his vanity, but it is difficult to decide on their authenticity. He wrote on a great variety of subjects, and his astronomical fame rests chiefly on his view that the apparent daily motion of the heavenly bodies is due, not to the rotation of the heavenly sphere, but to the rotation of the earth about its axis. He discovered that Mercury and Venus revolve round the sun (the sun was still assumed to revolve round the earth, circular motion being performed), and these two discoveries were an important step towards the Copernican theory.

The astronomical views of Aristotle (384–322 B.C.) are contained in two of his treatises—the *Meteorologica* and the *De Coelo*—and though he indulges in a considerable amount of criticism of other theories, his own are very interesting. Adopting the views of Eudoxus and Callippus regarding the concentric spheres, he argued on metaphysical grounds that their spheres would have a disturbing effect on one another, and to counteract this he introduced twenty-two fresh spheres, making a total of fifty-five. He treated the spheres as material bodies, and in consequence the geometrical scheme became a confused mechanism. Perhaps it is fortunate that Aristotle's spheres were not adopted by later leading Greek astronomers; if they had been adopted it is certain that the progress of astronomy would have been very much delayed.

Aristotle taught that motion in space is of three kinds—motion in a straight line, motion in a circle, and a third motion which is a combination of the first two. Because simple bodies have simple motions, it follows that the four elements tend to move

in straight lines; earth moves downwards, fire upwards; and between these two are the relatively heavy water and the relatively light air. He considered circular motion more perfect than motion in a straight line; hence it was necessary to postulate a fifth element, different from the other four, to which circular motion is natural. This fifth element, which occupies the outermost space, was called the "æther," and is more divine than the other elements just named. From it are formed the stars, which are eternal, intelligent, and divine, and it occupies all space from the outside limit of the universe to the moon, though it is not everywhere of the same density.

In common with other philosophers of his time, Aristotle believed that the heavens and all the heavenly bodies were spherical. He supports this view in the case of the moon by an appeal to observation, the phases of the moon being just what one might expect from a spherical body of which one-half only is illuminated by the sun. From the circular form of the boundary of the shadow of the earth cast on the moon during a lunar eclipse, he argues that the earth is spherical. Another reason for assuming the spherical shape of the earth is found in the changing positions of the stars as we move north or south, some of the stars disappearing and fresh ones taking their places. Another "proof" of the rotundity of the earth used by Aristotle is less convincing. He quotes the testimony of travellers from the far East and the far West (India and Morocco) that elephants existed in both places—from which he thought it might be inferred that the regions could not be very far apart. The readiness with which Aristotle and others admitted the spherical form of the earth and of the heavenly bodies was due to the esteem in which they held the circle and the sphere, as being "perfect" bodies. Incidentally this veneration for the "perfect" body retarded astronomical progress for many centuries.

The possibility of the revolution of the earth round the sun was rejected by Aristotle on the grounds that such a revolution would cause some apparent displacement of the stars, and, considering that in his day the immense distances of the stars were not known, this objection seemed a valid one. He discusses the question of

the distances of the various heavenly bodies, and concludes that the planets are farther off than the sun and moon, supporting this view on the very sound basis of the observation of an occultation of Mars by the moon. This does not, of course, show that the planets are farther off than the sun; but as an occultation of a planet by the sun was not observed, for the very good reason that it would be invisible in the intense glare of the sun, he concluded that the planets all lay beyond the sun. This shows that, in spite of some of his sage conjectures, he was lacking in the ability to apply certain well-known facts of nature to celestial phenomena. Regarding the stars, he merely quotes the opinions of the mathematicians that they are at least nine times as far off as the sun.

His astronomical speculations on the nature of comets, on the Milky Way, on the stars, on the reasons for the twinkling of stars, on the causes of the various celestial motions, etc., are of little value and need no further reference. On the whole, his original contributions to astronomy are much inferior to his contributions to other sciences—especially Natural History. What influence had Aristotle on the future development of astronomical science?

It was very unfortunate that the undeveloped Greek astronomy in the days of Aristotle should have crystallized in his works, with the result that his authority was cited for many centuries in support of doctrines which were utterly untenable, though they were plausible in Aristotle's time. It is unnecessary to multiply examples of his influence, and it will suffice to refer to the "perfect" figure which obsessed the minds of astronomers for centuries. Even Kepler, in the early part of the seventeenth century, attempted to adjust the motion of Mars to the perfect figure, and when he found it impossible to reconcile Tycho's observations with circular motion he tried the hypothesis of some form of oval curve. His delight was unbounded when he found that an ellipse completely satisfied the observations, and later he was able to apply elliptic orbits to all the planets. If only Aristotle and others had not expressed so much admiration for circular motion the course of astronomical development would have been very different.

The first astronomers of the Alexandrian school were Aristillus and Timocharis, who flourished about 300 B.C. under the first Ptolemy. Instead of merely announcing the rising and setting of stars, as had been done by the Babylonians, Egyptians, and early Greeks, they set out to determine the relative positions of the chief stars of the zodiac. Their work, to which we shall refer later, led to a very important discovery more than a century afterwards. Among the Alexandrian astronomers Aristarchus of Samos (about 310–230 B.C.) stands out prominently, and it is certain that he propounded the heliocentric hypothesis—a view for which Cleanthes the Stoic thought he ought to be indicted on the charge of impiety.

Aristarchus composed a treatise, *On the Magnitudes and Distances of the Sun and Moon*, which has been preserved to our times. In this treatise he describes his method for determining the relative distances of the sun and moon from the earth, and as a result of his work he concluded that the sun was between eighteen and nineteen times as far away as the moon. The method was quite sound in principle, and the error involved in it was due solely to the difficulty of determining accurately when the moon is half full. He found that when the moon was half full the angle subtended at the sun by the line joining the centres of the earth and moon was $3°$; its true value, however, is about $1° 10'$. In spite of this discrepancy the result had a good effect in expanding the notions regarding the boundaries of the universe, because the Pythagoreans had taught that the sun was, at the most, only three and a half times as far away as the moon. He further estimated that the apparent sizes of the sun and moon were equal, and from this inferred that their real diameters were proportional to their distances from the earth. Another important deduction which he made, based on eclipse observations, was that the diameter of the moon was about one-third that of the earth—a truly wonderful achievement, and not very far from the true figure, which is one-fourth. He measured the apparent diameter of the sun, and found it to be the 720th part of the circumference of the circle which the sun describes in his diurnal motion—an estimate also near the truth. He

believed that the stars were at immeasurably great distances from us in comparison with the sun's distance, and both his speculations and his actual calculations added considerably to the progress of astronomy. It is deplorable that Aristarchus found so few followers. The only person of note who is mentioned as having supported his view of the orbital motion of the earth round the sun, and also the diurnal rotation of the earth, in which he anticipated Copernicus, was Selecus, a Chaldean, who wrote on the subject of the tides about a century after Aristarchus.

Eratosthenes of Cyrene (276–195 B.C.) was the successor of Aristarchus, and was invited by Ptolemy Euergetes to Alexandria, where he was appointed keeper of the royal library. He is celebrated as the first who attempted, on scientific principles, to measure the size of the earth. He found that at Cyrene the sun was vertical at noon on the summer solstice, and that at Alexandria it was $7{\cdot}2^\circ$ from the vertical, at the same time; from this he inferred that the arc on the earth between Cyrene and Alexandria was to the circumference of the earth as $7{\cdot}2^\circ$ is to 360. By measuring the distance between Cyrene and Alexandria, which was 5,000 stadia, he was able to find the circumference of the earth. Unfortunately we are uncertain which stadium was used, so that we cannot be sure whether his results were as accurate as some have claimed. In addition, he assumed that Cyrene and Alexandria were on the same meridian, but this is far from being correct. Nevertheless, even if the error were as much as twenty per cent (as it would have been if he used the ordinary Olympic stadium) his result must be considered very satisfactory when compared with those of others, who often merely speculated on the size of the earth.[1]

Eratosthenes also measured the obliquity of the ecliptic, and found that it was $23^\circ\ 51'$. This observation was very important, though it was in error by about $7'$; theoretical considerations show that the angle is decreasing, and at the present time (1946) the obliquity is a little under $23^\circ\ 27'$.

[1] If it is true, as Pliny informs us, that Eratosthenes took an Egyptian schoenus equal to forty stadia, so that a stadium was equal to about 516¾ feet, his results gave the circumference of the earth as 24,467 miles.

Immediately after the days of Aristarchus, down to the time of Copernicus, the theory of epicycles and eccentric circles was used to explain the movements of the planets. We have seen that Heraclides was responsible for the idea that Mercury and Venus revolved round the sun, while the sun in turn revolved round the earth. If this took place the sun would be the centre of the epicycle, but in the case of the general epicycle the planet is supposed to move uniformly round the circumference of a circle, while the centre of this circle moves round a larger circle whose centre is the earth. The merit of suggesting that the motions of the heavenly bodies could be represented more simply by combinations of uniform circular motions than by the revolving spheres of Eudoxus and his school is usually attributed to Apollonius of Perga (about 265–190 B.C.). It is very uncertain, however, who first formulated the theory of epicycles, and while Apollonius discusses the epicycle and eccentric hypotheses, it does not appear that he was the actual originator of the idea.

Astronomy acquired a systematic form from the work of Hipparchus, who carried out his observations from approximately 161 to 126 B.C. He verified the obliquity of the ecliptic, which had been determined by Eratosthenes, and he found, by comparing his own observations with those of Aristarchus, that the accepted view of the length of the tropical year as 365¼ days was too long by about seven minutes. He discovered that the year is not divided by the solstices and equinoxes into equal parts—an observation which led to the important conclusion that the solar orbit was not circular—and from this in turn he was able to deduce that the solar days were not of the same length at different seasons of the year. He compiled tables of the sun's positions, the first ever mentioned in history. His researches on the motion of the moon led to very important results, among which may be noticed his determination of the period of the moon's revolution relatively to the stars, to the sun, to her nodes, and to her apogee. He also determined the eccentricity of the moon's orbit and the inclination of the orbit to the plane of the ecliptic. He approximated to the moon's parallax, which he attempted to deduce from that of the sun, and from his figures

he deduced that the greatest and least distances of the moon from the earth were seventy-eight and sixty-seven times the earth's radius respectively. From the sun's parallax he found that the distance of the sun was 1,300 times the earth's radius—a figure very far short of the true figure, which is about 24,000.

The apparition of a new star (134 B.C.) induced Hipparchus to compile a catalogue of the stars visible above the horizon, and this star-catalogue, which was completed about 127 B.C., contained 1,080 stars grouped in forty-eight constellations. When he compared his own observations with those of Aristillus and Timocharis he found that the first point of Aries had advanced two degrees in 150 years, and he was thus led to the very important discovery of the precession of the equinoxes. He invented the planisphere, by means of which the firmament could be represented on a plane surface, and he also demonstrated the methods of solving triangles—plane and spherical. He was the first to advocate the location of places on the surface of the earth by means of their latitudes and longitudes, and he determined longitudes by eclipses of the moon.

We agree with Delambre when he describes Hipparchus as "one of the most astonishing men of antiquity, and as the greatest of all in the sciences which are not purely speculative, and which require a combination of geometrical knowledge with a knowledge of phenomena, to be observed only by diligent attention and refined instruments." [1]

The last great name in Greek astronomy with which we are concerned at present is that of Claudius Ptolemæus, commonly known as Ptolemy, who lived at Alexandria about the middle of the second century A.D. His reputation rests chiefly on his astronomical treatise, the *Almagest*, which is the source from which most of our knowledge of Greek astronomy is derived. This work held the field until the days of Copernicus, and was regarded as the standard astronomical text-book until the Middle Ages. It is remarkable that Ptolemy himself contributed very little of serious value to the work; it was largely a compendium of the work of others—Hipparchus in particular. Among Ptolemy's

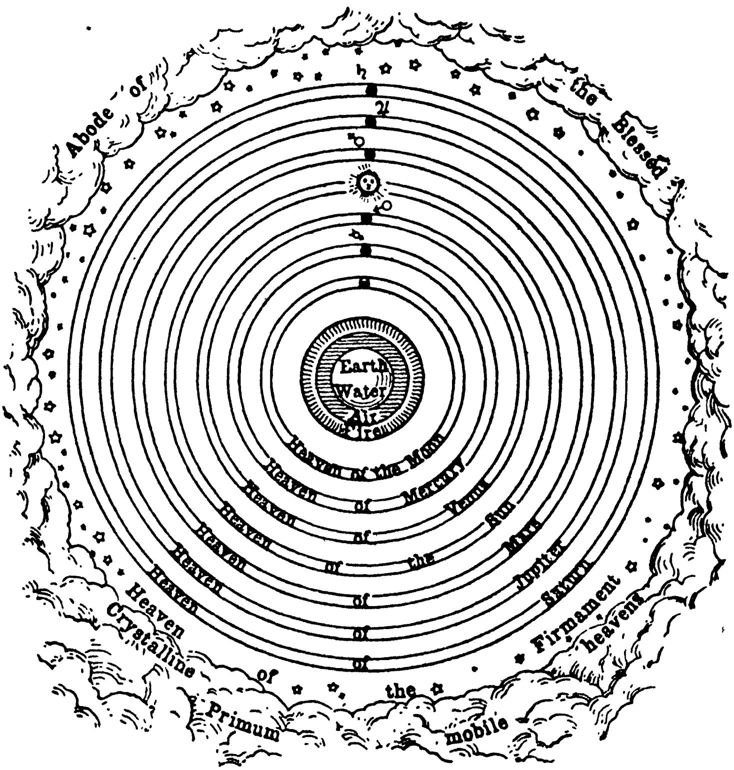
[1] *Histoire de l'Astronomie Ancienne*, Vol. 1, p. 185.

own contributions may be noticed a simple method for finding the moon's parallax, the variation in the eccentricity of the lunar orbit, and the motion of the five planets, for which Hipparchus had collected material in the shape of observations made by earlier astronomers and by himself. The Ptolemaic theory, with which his name is widely associated, regarded the earth as the immovable centre of the universe, round which the sun, the moon, and the entire heavens completed a revolution in about twenty-four hours. The motion of a planet relative to the earth was compounded of a motion round a circle, which was called an epicycle, the centre of this circle travelling along the circumference of a larger circle called the deferent. The sun moved in a circular orbit between the deferents of Venus and Mars. The complicated movements of the planets could not be fully explained by this system, and Ptolemy introduced a number of additional hypotheses which represented fairly accurately the motions of the planets as given by the data in his possession. We need not deal with these additional hypotheses, the development of which involved a considerable amount of labour, except to point out that the use of his *equant* was an obvious violation of the principle, on which the system was supposed to be based, of using only uniform circular motions. Either Ptolemy was unconscious of the inconsistency or he did not adhere rigidly to the fetish of uniform circular motion.

The history of Greek astronomy practically ceased with Ptolemy, and the practice of observation almost completely died out. The only Greek writers after Ptolemy are compilers and annotators, to none of whom we can attribute important original ideas. The murder of Hypatia, in A.D. 415, marks an epoch in the decay of the Alexandrian school, and when the Arabs captured the city, in A.D. 640, Greek culture came to an end.

The legislation of Solon (about 638–559 B.C.) largely moulded the subsequent political life of Athens. Not only did his age witness a social and political movement among the masses in various parts of Greece; there was an intellectual and spiritual stirring as well. As an explanation of the origin of the world, the theogony of Hesiod proved unsatisfying, and largely as a

consequence the natural philosophy of Thales and his successors arose in Ionia. This rise of Rationalism probably saved Greece from a dead and stifling weight which might have had disastrous consequences for her future. In addition to the intellectual




[From *Religion in Science and Civilization*, by Sir Richard Gregory (*by permission of Macmillan & Co., Ltd.*).

FIG. 6.—THE PTOLEMAIC SYSTEM.

dissatisfaction, there was a spiritual dissatisfaction; men craved for some knowledge of existence after death and for contact with the supernatural. Both these movements—the rational and the spiritual—had one and the same object in view: to solve the

mystery of existence. In consequence of the religious stirring, a new faith began to spread about the middle of the sixth century before Christ. It was based on the Thracian worship of Dionysus, and was called Orphic, from the poet and priest Orpheus, who was supposed to have founded the Bacchic rites.

The Orphic teachers—many of them itinerant seers who travelled over the country and made a living by prophesying, purifying, and pretending to heal the sick—promulgated a new theory of the creation of the world which suggests a Babylonian origin. Time was the original principle, and afterwards Ether and Chaos came into existence; from these two elements Time formed a silver egg. Out of this egg there sprang Phanes, god of light, and they taught that the development of the world is simply the self-revelation of Phanes. This cosmogony did not fit in well with Greek theology, so it was necessary to adjust it to suit the latter. For this reason Zeus is made to swallow Phanes and so become the original force from which the world has to be developed anew. Dionysus Zagreus, the Thracian god, is the son of Zeus and Persephone, and while he is still a boy his father gives him the kingdom of the universe. The Titans—a gigantic race which inhabited the earth before the creation man—pursued Dionysus Zagreus, and after many escapes, and finally taking the shape of a bull, he is rent in pieces by the Titans. His heart was saved by Athena, and was afterwards swallowed by Zeus, who brings forth a new Dionysus, and when Zeus strikes the Titans with lightning a race of men springs from their ashes.

We can see from this myth that the nature of man is compounded of two elements—the good from Dionysus and the bad from the Titans—and the motive in the myth is to remind men of their divine origin and to assist them to regain their divine state. Many penalties and purifications are necessary to become free from the Titanic elements, and the soul has to pass through a number of incarnations; in the intervals between these incarnations it exists in the kingdom of Hades.

It seems remarkable that the Orphic doctrines should have been taken up by Pythagoras, to whom we have already referred (p. 43). He founded a religious brotherhood at Croton and

organized it according to strict rules. Pythagoras was a mystic philosopher—a fact which explains many of his extraordinary mental aberrations. He speculated on certain mystic properties of numbers and music, and in accordance with these speculations he thought that the heavenly spheres (see p. 45), as they revolved, produced harmonious sounds which might be heard at times by specially gifted persons. This is the origin of the idea of "the music of the spheres," which recurs frequently in medieval literature and is found even in modern literature.

The brotherhood founded by Pythagoras was of an Orphic character and claimed many adherents of both sexes in Croton and neighbouring cities. It became a strong political power, and when war broke out between Croton and Sybaris the Sybarites were defeated and their city was destroyed. The destruction of this rival city was a great exploit for the Pythagoreans, but soon afterwards a reaction set in and Pythagoras fled from Croton. In 450 B.C. the Pythagoreans were suppressed, the members being banished or put to death wherever they were found in Italy.

While the Orphic religion was not a danger to Greece at the time of the fall of the Pythagoreans, there was, nevertheless, during the lifetime of Pythagoras, the possibility of its doctrines spreading and taking hold in Greece. Had this happened, the priesthoods of the national temples, accepting the new religion and becoming its ministers, would have attained a dominating position throughout the country; as it was they exercised a powerful influence, even diffusing a very vivid picture of Hades which affected subsequent literature. It was fortunate that the Ionian School under Thales arose, because the Ionian philosophy acted in such a way that it counteracted the tendencies of the Orphic religion. Europe owes a debt to Ionia for having founded philosophy, and by so doing rescuing Greece from the tyranny of a religion interpreted by priests. It is true that astronomy was only one of the sciences dealt with by the Ionian philosophers, but it is difficult to apportion the honours to the various fields of human activity. Some reference, however, is due to Xenophanes, who was born about 570 B.C., and lived to a great age.

Xenophanes constructed a philosophy of which the first

principle was God, which he identified with the whole cosmos. He rejected the Orphic religion just as he rejected Hesiod. Mysticism and divine revelation found no place in his teaching, and he regarded the Orphic priests as impostors. In this way he rendered signal services not only in his own generation but also to posterity, in combating the dangers of the Orphic religion, and by the time of his death Greek philosophy had become such a force that sacerdotalism was powerless to check its progress.

Although the opinions of Xenophanes on the form and nature of the world are extremely crude, there was nothing occult or mystic about his views, and in one of his poems he says that certainty of knowledge is unattainable. He was sufficiently observant to notice that shells are found on dry land and even on mountains, while in different places, such as the quarries at Syracuse, imprints of fish and of seals were observed. He did not formulate any far-fetched theories, to explain fossils, such as has been done in comparatively recent times, but offered the rational explanation that the imprints were made a long time previously, when everything was covered with mud, and the imprints then dried in the mud. He thought that the earth would finally sink into the sea and become mud again, after which the human race would begin anew.

The influence of the immortal philosophers of Ionia averted a great peril from Greece, but, taking a wider view, it would be more correct to say that the victory of philosophy over mysticism was simply the expression of the Greek spirit seeking satisfaction in expanding its own powers in the light of reason.

Vitruvius informs us that the introduction of astrology into Greece was due to Berosus, a Chaldean priest, who lived in the fourth century B.C., but the actual birth of Greek astrology can be placed somewhere about 280 B.C. In certain respects it is not surprising that Greek culture favoured astrology. The Greeks had noticed in their study of meteorology that certain stars or constellations were associated with certain conditions of the weather, and there was nothing mysterious about this. In our islands we are aware of the fact that certain constellations are most prominent in the heavens during the spring, others during

the autumn, and so on, and hence we naturally associate these constellations with various conditions of the weather. We do not, however, believe that there is any occult connection between the stars and the weather, but unfortunately this view prevailed among the Greeks. They believed also that there was some form of affinity between the stars and men's souls, and, in addition, that a genius took charge of a person at birth, this genius being connected in some manner with the star that presided over the birth.

## CHAPTER VI

# HEBREW ASTRONOMY

If the Greeks claim the honour of creating the beginnings of science, the Hebrews can claim the honour of attempting to purify religious sentiment and to prepare the way for monotheism. It is only necessary to read their ancient literature to realize that they possessed very little natural gift for scientific discoveries or for formulating scientific theories; both science and art, for them, were of secondary importance. Although this ancient literature shows the crude nature of their cosmogony, it must not be assumed that the Hebrews were lacking in lofty conceptions of the wonders of creation. In the Psalms and the Book of Job, and also in some of the prophets, we find some beautiful portrayals of Nature, and in the wonders of the world the Hebrew seer sees an expression of the power of God. Many of these poems—more especially some of those found in the Book of Job—are grand and solemn in their delineation of the works of Nature. One feels, when reading, them that it is possible to forget the crude cosmogony; and indeed in many cases they would lose much of their beauty if this naïve cosmogony were eliminated.

This does not imply that the Hebrews had always a very high conception of the Creator; indeed, their god was for many centuries little more than a tribal god; yet, taken on the whole, he was better than the gods of the Greek pantheon. It is true that often he appears as extremely jealous of other gods and very vindictive. He had special delight in offerings of animals, and Cain's gifts of the fruits of the earth were not acceptable to him, though those of Abel, who brought the firstlings of the flock and the fat thereof, were favourably received. He was capable of putting lying spirits into the mouths of the prophets to deceive those whom he had decided to destroy, and he could instigate Joshua's fighting forces to annihilate their enemies completely, sparing neither women nor children. He did not hesitate, as we read in the second commandment, to punish children for the

sins of their fathers, and this punishment seems to have been inflicted more especially if any other gods except himself were worshipped. These low views of their god were quite consistent with a limited knowledge of the universe, or perhaps it would be more correct to say that they were partly an outcome of this limited view. To understand this more fully it will be necessary to deal with the Hebrew conception of the universe.

There was nothing essentially different between the Hebrew view of the universe and that of many other primitive peoples. This is not surprising when it is remembered that primitive people judge largely by appearances. For example, appearances suggest very strongly that the earth is flat. There is a story told about President Kruger, who accepted the Bible as literally accurate and believed from its evidence, and also from the evidence of his senses, that the earth was flat. When someone tried to explain to him that it was spherical and that the flat appearance was really misleading, Kruger merely replied: "But surely you can see that it is flat." If the story is true—and there is no reason for doubting it—he was just reasoning in the way that men reasoned for thousands of years, and as some very backward races reason to-day.

The Hebrews regarded the earth as nearly flat, its extreme parts supporting the heavens, which were supposed to be like a large vault. The heavens included all the upper part of the world, and the stars existed in its highest part. The mass of the earth and the sea formed the lower part of the universe or the abyss where great masses of water were collected; in the words of Psalm xxxiii, 7, "He gathereth the waters of the sea together as an heap; he layeth up the deeps in storehouses" (R.V.). We read in Genesis vii, 11, and also in viii, 2, about the fountains of the deep; the Hebrews believed that this great mass of subterranean water was able to burst forth and to contribute to the deluge. Springs and the sources of rivers also proceeded from this supply, and in Proverbs viii, 24, we are told that wisdom existed before there were depths and fountains abounding with water. In Psalm xviii, 15, the writer gives a description of some of the works of Nature, including the appearance of the channels

of water and of the foundations of the world (v, 15). These subterranean waters partly rose by means of channels to the surface of the earth, and were responsible for springs and rivers. No natural explanation was afforded of the rise of these lower waters against the force of gravity, and it was accepted as a result of the divine omnipotence. Amos describes how the Lord "calleth for the waters of the sea and poureth them out upon the face of the earth" (v, 8).

In the lower portion of the abysses is Sheol, so vividly described in the book of Job as "the land of darkness and of the shadow of death; a land of thick darkness, as darkness itself; a land of the shadow of death, without any order, and where the light is as darkness" (x, 21–2). Ezekiel regards a part of Sheol as deeper, and calls it the pit, and this portion seems to have been reserved for the Gentiles, or at least for the uncircumcised (xxxii, 19), or for those who have fallen by the sword (xxxii, 20). In time the upper part of Sheol came to be regarded, not as a place of terror and of punishment, but as a dwelling-place for the righteous, and it was called Abraham's bosom (St. Luke xvi, 22). The lower part was a place of torment (St. Luke xvi, 23). In verse 26 reference is made to the gap separating the two regions so that it was impossible for the souls in one place to pass over to render assistance to those suffering torment in the other.

The system of the heavens rose above the surface of the great circle occupied by the earth and seas, and in the Vulgate it is rendered by *firmamentum*, from which we derive our well-known word firmament. This firmament was believed to be very strong, as we learn from Job xxxvii, 18, where it is described as "strong as a molten mirror." It supported the upper waters (Genesis i, 7), and these waters are exhorted to praise God (Psalm cxlviii, 4). The stars are placed higher than this vault, which, as it was believed to be transparent, allowed their light to pass through. From various passages in the Bible it is certain that the Hebrews imagined that great flood-gates existed, by means of which the upper waters could be distributed over the earth in the form of rain. In Genesis vii, 11, we read about the windows of heaven being opened, the fountains of the great deep being also broken

up, to produce the deluge. These flood-gates were directly controlled by Yahwe (Jeremiah v, 24), and in Job xxviii, 25, we are told that he "meteth out the waters by measure." In Leviticus xxvi, 3, and also in Deuteronomy xxviii, 12, it is clearly laid down that the gift of rain from the treasury is conditional on the observance of certain ordinances; hence a drought would naturally be interpreted as a sign of the divine disfavour.

It was obvious to the Hebrews, in spite of their crude conceptions regarding natural phenomena, that a convex dome could not retain water unless there were another vault above it. Such a vault was supposed to exist and, with the firmament, enclosed a space where are the storehouses of the rain, hail, and snow. The Book of Job speaks of these when the Lord was supposed to have answered Job out of the whirlwind: "Hast thou entered the treasuries of the snow, or hast thou seen the treasuries of the hail?" (Job xxxviii, 2). The snow and rain are under the direct control of Yahwe and fall on the earth only by his command (Job xxxviii, 6). There does not appear to have been any knowledge, even in the days of Isaiah, about 540 B.C.,[1] of the evaporation of water from the sea and its return to the earth; we read in Isaiah lv, 10: "For as the rain cometh down and the snow from heaven, and returneth not thither, but waterest the earth, and maketh it bring forth and bud, and giveth seed to the sower and bread to the eater, so shall my word be that goeth forth from my mouth." Although there was some knowledge about vapours ascending, often there was no apparent connection between this phenomenon and the clouds. In Psalm cxxxv, 7, we read: "He causeth the vapours to ascend from the ends of the earth; he maketh lightnings for the rain; he bringeth forth the winds out of his treasuries," and the same idea is expressed by Jeremiah (x, 13, li, 16). The treasuries or storehouses of the winds were supposed to be situated on the level of lands and seas, and, as they could be opened from one side or another, the wind could come from various directions, though we find that only four directions were recognized. In Ezekiel xxxvii, 9, the writer speaks of the four

[1] This date refers to the writer of Isaiah xl–lx, who probably wrote this portion towards the end of the Babylonian Captivity.

winds, and a similar allusion is made in Daniel viii, 8, and in other parts of the Bible. The four winds corresponded to the cardinal points, and they were indicated, just as with us, by the name of the direction from which they blew. Reference has just been made to the clouds, which were not always associated with the rising vapours, and it is difficult to understand why such an obvious connection should not have been noticed. The rainbow was supposed to be set in the clouds (Genesis ix, 13, 14, 16), and even in the days of Ezekiel the same belief clearly prevailed (Ezekiel i, 28).

It must be admitted, however, that it is very difficult to present an accurate account of the Hebrew writers' conceptions of meteorological phenomena, because in some cases they may have used metaphorical language. As an instance, reference may be made to a number of passages which show that the writers were aware of a definite connection between the clouds and rain. For example, Job mentions this connection on some occasions (xxvi, 8, and 27–8), and it was known to the writers of Ecclesiastes (see xi, 3), to the writer of the Book of Judges (v, 4), and to others. As the Hebrew writers often used natural phenomena to show the wondrous power and wisdom of Yahwe, and were primarily concerned with setting forth the latter, they were not always careful about making a very critical study of nature, and probably errors in the presentation would not be detrimental to their views about Yahwe.

A rough diagram shows what was probably the Hebrew conception of the universe, including the heavens, the earth, and the abysses (see Fig. 7).

The stars were not set in the firmament, which was solid, like a molten mirror, but were set in something which was flexible, like a curtain. Thus in Isaiah xi, 22, we read: "It is he that sitteth on the circle of the earth, and the inhabitants thereof are as grasshoppers; that stretcheth out the heavens as a curtain, and spreadeth them out as a tent to dwell in." The same expression is found in Psalm civ, 2, and in various other parts of the Bible. So flexible and frail was this curtain or gauze, as the word could be rendered, that Isaiah sees the whole structure rolled

together as a scroll (xxxiv, 4). The Lord's indignation against the nations is so great that " . . . all the host of heaven shall be dissolved, and the heavens shall be rolled together as a scroll; and all their host shall fade away. . . ."

Although, as we shall see, certain stars were well known to the

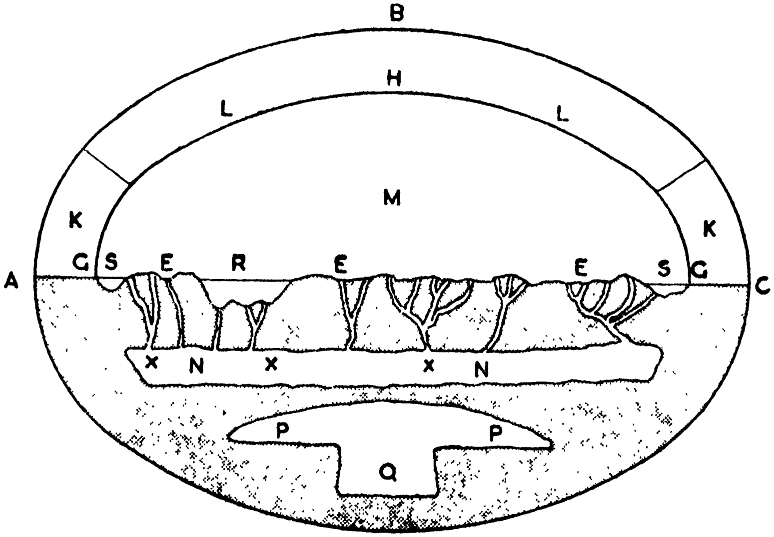



FIG. 7.—THE UNIVERSE ACCORDING TO THE WRITERS OF THE OLD TESTAMENT

ABC represents the upper heaven; AC the curve of the abyss; AEC the plane of the earth and seas; SRS various parts of the seas; EEE various parts of the earth; GHG the profile of the firmament, or lower heaven; KK the storehouses of the winds; LL the storehouses of the upper waters, of snow, and of hail; M the space occupied by the air, within which the clouds move; NN the waters of the great abyss; XXX the fountains of the great abyss; PP Sheol, or limbo; Q the lower portion of Sheol—the Inferno.

Hebrews, the power of knowing all of them was reserved for God (Psalm cxlvii, 4), and in Job xxxviii, where God is represented as speaking to Job, man's ignorance is contrasted with the knowledge of God: " Knowest thou the ordinances of the heavens? Canst thou establish the dominion thereof in the earth?" (verse 33). The apparent motions of the stars were, of course, known, but it was not suspected that the movement

was due to the rotation of the earth on its axis. In Judges v, which contains the song of Deborah and Barak after the overthrow of Sisera and his host, verse 20 contains the phrase, " The stars in their courses fought against Sisera," an allusion to the motions of the stars as they appeared to the writer and author of the song.

The sun is described in Psalm xix as a magnificent part of creation: " His going forth is from the end of the heaven, and his circuit unto the ends of it; and there is nothing hid from the heat thereof" (verse 6). In Ecclesiastes i, 5, the subterranean course of the sun is indicated: " The sun also ariseth, and the sun goeth down, and hasteth to the place where he ariseth." The moon was very useful for fixing the dates of feasts, etc., and special reference will be made later to the observation of the moon and to her importance. Of course the moon, like the sun, was believed to move round the earth, which was of much more importance than either of these bodies. It is not surprising that the course of the sun and moon could be arrested by Joshua when he required a longer day to discomfit his enemies; but it is remarkable that we are not informed whether he ordered them to continue on their course after his victory over his enemies, though their subsequent motion might be inferred from Joshua x, 13, last portion of the verse. As the greater part of verses 12 and 13 are merely quotations from the *Book of Jasher* or of *the Just*—a collection of songs connected with the heroic deeds of great men —we need not take the story very seriously. It is rather deplorable that so much has been written to explain this "miracle," which must be relegated to the realm of poetic imagination and licence. Eastern writers had a remarkable gift of imagination, and the Western mind has often misunderstood their metaphors and exaggerated forms of expression. Perhaps our descendants will some day lack completely the power of imagination and will condemn Tennyson for his apparent ignorance in making use of the words: " Urania speaks with darken'd brow."

Hebrew writers describe eclipses of the sun and moon, which they regarded as signs of divine displeasure. The prophet Joel, who depicted the most terrible calamities for the land, speaks of the sun being turned into darkness and the moon into blood,

before the great and terrible day of the Lord come (ii, 31), and we find that the prophet Amos uses similar words (viii, 9). The livid reddish colour which is frequently noticed during an eclipse of the moon was responsible for the expression " the moon turned into blood," and such a colour would naturally suggest imminent disaster.

The Hebrews were not aware of the existence of more than two planets, and the appearances of Venus in the morning and evening were regarded as due to two different stars. In Isaiah xiv, 12, the writer is rejoicing over the fall of the Babylonian Empire, and he compares its king to the day star: " How art thou fallen from heaven, O day star, son of the morning! " The reference is almost certainly to Venus. Prof. G. Schiaparelli thinks that the word *mazzaroth* (2 Kings xxiii, 5) is the name applied to the apparently two different stars—actually Venus. He also thinks that in Amos v, 26—" Yea, ye have borne Siccuth your king and Chiun your images, the star of your god, which ye made for yourselves "—there is an allusion to the planet Saturn, which the Jews worshipped, thus earning reproof from the prophet. Among the ancient Arabs, and also among the Assyrians, *Kaivan* was the name of Saturn, and *Chiun* was probably a reference to the same planet.

Comets and meteors and also meteorites were known to the Jews. When Joel speaks of " pillars of smoke " (ii, 30) he may be referring to the appearance of comets. In Genesis xv, 17, the words " a smoking furnace and a flaming torch " probably relate to a fireball, and the allusion in St. Luke x, 18, to Satan falling as lightning from heaven was possibly inspired by a bright meteor or a fireball. Joshua x, 11, mentions meteoric stones which fell on the enemy during the battle and caused many deaths. These stones were supposed to have been due to the direct action of Yahwe, who cast them from heaven, but as " hailstones " are also mentioned in the passage, it is possible that the missiles were only very large hailstones.

Some of the constellations were well known, as we find in the Book of Job, and when we come to the last kings of Israel we know that the worship of the stars was prevalent. The use of the phrase

*the host of heaven* is common at this time, and this form of worship was introduced under the influence of the Assyrians. In 1 Kings xxii, 19, there is a description of the Lord sitting on his throne and all the host of heaven standing by him. The narrative assumes that they were sitting in council and that there were good and evil spirits ready to execute the will of the Lord. The influence of Babylonian theology is evident here. Not only did that theology teach the worship of the sun and the moon and the planets; it also introduced a number of spirits, malignant and good, associated with particular stars or groups of stars (called the host of heaven), which were objects of superstitious veneration. In the hymn of Marduk—the Merodach-baladan in Isaiah xxxix, 1—the angels of the hosts of heaven and earth are said to belong to Marduk.

Not only did the Jews practise star-worship; it seems probable that astrology was also practised by them, and that it was introduced by the Assyrians and the Babylonians. During the Babylonian Captivity (586–536 B.C.) there was an opportunity of learning from the civilization of the Babylonians, but unfortunately there was also the opportunity of learning much that was degrading. Isaiah (xiv, 11, 13, 14) says: "Thou art wearied in the multitude of thy counsels; let now the astrologers, the star-gazers, the monthly prognosticators, stand up and save thee from the things that shall come upon thee." The prophets set themselves firmly against the worship of the stars and astrology, and Jeremiah warns his people not to be dismayed by the signs of the heavens, at which the Gentiles are dismayed (x, 2). Star-worship and astrology finally ceased, so the warnings of the prophets had some effect.

## CHAPTER VII

# HEBREW ASTRONOMY (*continued*)

WE have already seen that the Babylonians reckoned the day from evening to evening, and the same custom prevailed among the Jews. In the story of Creation recorded in Genesis i the evening precedes the morning in the description of each day. That this is not a peculiarity of the writer is shown by the adoption of the same form in other parts of the Bible. Thus in Psalm iv, 17, we read: "Evening, and morning, and at noonday, will I complain, and moan." Jewish festivals were arranged to last through one or more complete days, beginning and ending with the evening. Thus the Day of Atonement began in the evening (Leviticus xxiii, 32), and the feast of the Passover (Exodus xii, 18), which began in the evening from the earliest times, was still observed in the same way in the days of Christ; hence the anxiety that the bodies of those who were crucified should not remain on the cross on the sabbath, for the day of that sabbath was a high day—that is, the Feast of the Passover (John xix, 31).

The reason for beginning the day in the evening is found in the fact that the beginning of the months was reckoned from the instant when the luminous crescent of the moon became visible. As the new moon would be seen in the dusk at the twilight of evening, it was natural to start the day in the evening. There must have been many occasions when it was impossible, owing to local conditions, to observe the new moon, and in such circumstances it is probable that the days were numbered from 30 to 30 to fix the beginning of the month. It is certain that the date of the new moon could be estimated in advance, as is proved by the words of David to Jonathan: "Behold, to-morrow is the new moon" (1 Samuel xx, 5, 18, 24, 27). In the days of Saul, the first king of Israel, the beginning of the month was apparently recognized as a solemn occasion, as David was then expected to sit at meat with the king. In Hosea and in other parts of the Bible we find allusions to religious rites on this day (Hosea ii, 11, Amos viii, 5, Isaiah i, 13, 14, etc.).

Just as the moon was used to determine the months, so the sun served to determine the length of the year. From indirect evidence in Genesis it appears that the Jews had some knowledge of the length of the tropical year. We are told that Enoch lived 365 years (Genesis v, 24), and this number can scarcely be considered a coincidence. Again, the writer of Genesis vii, 11 and viii, 4, makes the flood begin on the seventeenth day of the second month, and the drying up of the earth on the twenty-seventh day of the second month a year later. Taking these months as lunar

[From *Stars and How to Identify Them*, by E. W. Maunder (*by permission of The Epworth Press*).

FIG. 8.—ANNOUNCEMENT OF THE NEW MOON AMONG THE HEBREWS.

periods, twelve of them would amount to nearly 354½ days, and the extra days would imply that the flood lasted almost exactly 365 days. It may be remarked at this point that the number of years attributed to Adam and some of his descendants (Genesis v) —from Seth to Lamech—is explicable if the "years" were months, as seems probable. In the next chapter we are told that Jahwe limited man's days to one hundred and twenty years. This appears to have been ordained to eliminate as quickly as possible the divine principle in man introduced by "the sons of

God" who married the daughters of men, and produced a race of giants, the Nephilim, of whose divine principle Jahweh seems to have been jealous. It is possible that the writer[1] of this portion accepted the longevity of Adam and his descendants as literally accurate and was not aware of the fact that their ages were reckoned in months.

If the Jews had been content to count twelve moons in the tropical year there would have been a discrepancy of eleven days each year, and they would have been confronted with the same problem as is found in the Mohammedan Calendar, in which each year consists of 12 lunar months. Each month goes the round of the seasons in 33 years, or three times in a century. To avoid this confusion an inter-calendary month must have been adopted, although there is no direct evidence that this was actually done in early times. It has been suggested that there is an allusion to it in Deuteronomy xvi, 1, where we read: "Observe the month of Abīb, and keep the passover unto the Lord thy God." If careful observation were kept on blossoming time and the progress of the months afterwards, when the ears started forming, it was easy to make the necessary alterations in the Calendar. Of course climatic conditions varied somewhat from year to year, and hence difficulties might occasionally arise, but generally speaking the method adopted worked sufficiently well for the purpose.

Considering the dates at which barley, wheat, and vines ripen in Palestine, the beginning of the year fell on the first or sometimes on the second new moon after the spring equinox. This necessitated changes in the date of the passover, and other feasts as well, the passover occurring from the first ten days of April to the first ten days of May. This inconvenience of a varying date for important religious observances was accepted without complaint to allow for the inter-calendary month, which was placed thirteenth on the list of months after the return from the Babylonian Captivity, and was named Veadar—meaning "Adar again." Adar was the name adopted for the twelfth month after

[1] Most of Genesis v belongs to the P code, whereas the first eight verses of Chapter vi belong to the J code.

the exile, and was derived from the Babylonian name for the month—" Addaru."

The descendants of the ancient exiles who found toleration under the Arsacidæ—the dynasty of the Parthian kings—are said to have attained both material prosperity and also intellectual growth. Rabbi Samuel and Rabbi Adda taught astronomy in the first half of the third century of the Christian era, and were able to make accurate calculations of the new moons and equinoxes. The cycle of 84 years adopted by the Jews, after their dispersion, to regulate their religious festivals all over the world was abandoned in A.D. 360 in favour of the Meton cycle. Rabbi Samuel was the first to suggest this improvement, and the Jews still adhere to it. They say it will continue until the coming of the Messiah.

The month was inconvenient as an interval of time for religious feasts or for commercial purposes. Markets that occurred only once a month would not have served the needs of people in a progressive civilization, and for these reasons cycles embracing a smaller number of days were introduced. Before the Spanish conquest of Mexico we find that there was a period of five days, and among the ancient Egyptians a ten-day period was in use, while the Romans in republican times made use of an eight-day period. The five-day and the ten-day periods, being the one-fourth and the one-third of a month, were convenient, but the same can scarcely be said of the eight-day period. (The Mexican month was only 20 days long, so five days were one-fourth of their month.)

The length of a lunar month is about 29½ days, and as one-fourth of this is 7 days and a fraction of a day, it was natural that a seven-day period should arise. This form of week was in use among the ancient Babylonians, and a portion of a Babylonian calendar preserved in the British Museum shows that the seventh, fourteenth, twenty-first, and twenty-eighth days of the month were marked as unlucky days. Although the ordinary people were allowed to proceed about their usual business on these days, there were severe restrictions for persons in higher positions. Thus the king was obliged to abstain from eating certain foods,

from making State decisions, from going out in his chariot; doctors were not allowed to lay hands on the sick, while even the priests themselves were forbidden to utter oracles.

Certain disadvantages arose where this system was adhered to rigorously, reckoning the days from the beginning of the month or from new moon and leaving a day or two over at the end so that the reckoning could begin again from the first of the following month. In time a conventional week came to be recognized, and this was not subject to the uncertainties attending the determination of the new moon, so that the week was established on a basis similar to that which we have at present.

How did the Jews arrive at their conception of the week, and why did they attach such importance to a correct observation of the seventh day of the week? These are not easy questions to answer, and we can only say that the Sabbath was recognized as an enforced rest from the earliest times in the history of the people. When the Jews were carried into captivity their week seems to have been adopted by the Babylonian astrologers for divination purposes, and later it was accepted, with certain modifications, by the Christian and Mohammedan nations. The Christians adopted the first day of the week as their day of rest and worship, and the Mohammedans adopted the sixth day—Friday—so that one day in seven is recognized throughout a considerable part of the civilized world to-day as a day of rest and worship, though the observation of the latter is rapidly disappearing.

It has been suggested that the seven-day week originated from the knowledge of the seven "stars" in the ecliptic, which are visible to the naked eye: that is, the sun, moon, Mercury, Venus, Mars, Jupiter, and Saturn. This suggestion is untenable so far as the Babylonians were concerned, because their calendar, already referred to, makes no mention of the planets or of their corresponding deities, and their week was based upon lunations. It is also impossible to retain this view about the Jewish week, because it was established before the Jews had much knowledge about the planets or any other heavenly bodies. The identity of the number of days in the week with the number of planets

cannot be regarded as anything more than a pure coincidence, and the mystery regarding the Jewish week remains inexplicable.

Before concluding this account of Hebrew astronomy something should be said about the temple built by Solomon (1015–980 B.C.). The work was started in the fourth year of his reign and completed in seven years: a description of it is given in Chronicles ii, 2 *et seq.*, and also in Kings ii, 6, *et seq.*, with various differences in the details. Josephus, the Jewish historian, who lived about A.D. 38–100, informs us, in *Antiquities*, that the temple was oriented to the east with great care. In plan it was like some of the Egyptian temples (see p. 24), the light from the sun being free to shine through an open passage and to enter the Holy of Holies. The direction of the axis of the temple shows that there was a cult interested in the possibility of seeing the sun rise at one of the equinoxes. The sunlight would penetrate over the high altar into the Holy of Holies, and the worshippers would see the high priest by means of the sunlight reflected from the jewels in his garments. As their backs were turned to the sun, which was rising due east, the effect of the sunlight would be very spectacular. The High Priest entered the Holy of Holies once a year only, though the effect described above would have taken place twice a year, once about the time of each equinox. Josephus informs us that the stones which the high priest bore on his shoulders were sardonyxes and that one of them shone out when God was present at their sacrifices:[1] "I mean that which was of the nature of a button on his right shoulder, bright rays darting out thence, and being seen even by those who were most remote; which splendour yet was not before natural to the stone"[2]

This phenomenon did not continue indefinitely, and Josephus tells us that it ceased two hundred years before his time, "God having been displeased at the transgression of His laws." What explanation can we give of the cessation of this "miraculous" shining of the jewels?

[1] See Exodus xxviii for a description of the garments worn by the high priest.

[2] *Antiquities*, iii, c. 8, § 9.

An astronomical suggestion [1] has been made which helps to solve this problem. In the earliest times equinoctial temples were solar temples, and the rising sun would, provided the weather were fine, shine on the altar at the equinox, marking New Year's Day. When later Babylonian astronomy replaced the sun by the moon, the year did not begin with the equinox, but with new or full moon near the equinox. One of these occasions might occur at the equinox, and if so the phenomenon would still appear, but in most cases the sun would be too far from the east at the relevant time—the beginning of the reformed new year—to shine on the high priest as he ministered at the altar. In this way it is possible to explain the withdrawal of the sunshine from the temple.

The building of the temple implied that a more national form was given to the system of worship, and at this time Canaanite names for the months were abolished and numbers were adopted. Thus in 1 Kings vi, 1, the month Ziv is described as the second month. In the ancient order Ziv was the eighth month and Abīb the seventh month, the latter corresponding approximately to our April. The old Jewish calendar was identical with that of the Phœnicians or the Canaanites, to whom the Phœnicians were closely related. It is not surprising that at the building of the temple an attempt was made to abolish everything that suggested the abominations of the Canaanites, and this explains the adoption of numbers for the months, the first month starting the year. Hence Abīb, which was formerly the seventh month, now became the first month. Denoting the months by numbers is found in some of the early books of the Bible (see for instance Genesis vii and viii), but many of these books, though dealing with ancient history, were written after the days of Solomon. We know the names of only four of the Canaanite months; these appear in Exodus xxxiii, 15, 1 Kings vi, 1 and 37, and 38, 1 Kings viii, 2, and are respectively, Abīb, Ziv, Bul, and Ethanim.

Although the temple worship served to unify the religion of the people and to eliminate everything that was suggestive of the

[1] Sir Norman Lockyer deals with this point in *The Dawn of Astronomy*, Chapter IX.

hated worship of the Canaanites and others, the period of the exile was responsible for the introduction of many customs which were once abhorrent to the Jewish mind. We have already referred to star-worship and astrology; another innovation was the adoption, with slight modifications, of the Babylonian names for the months. The Assyrio-Babylonian cuneiform inscriptions show that the names used in Babylonia, which were adopted by the Assyrians, and in part by the Aramæans of Northern Syria and Western Mesopotamia, passed into the Jewish calendar. Nisan became the name of the first month, and the names of the others in order were Iyar, Sivan, Tammuz, Ab, Elul, Tishri, Marhesvan, Kislev, Tebeth, Shebat, Adar. These names appear first in the Book of the prophet Zechariah, who wrote soon after the return from captivity.

This survey of Hebrew astronomy has been elaborated rather more fully than those concerning some other ancient peoples, and it is hoped that readers will not feel weary of details which seem to have little bearing on modern astronomical thought. It must be remembered, however, that the Christian religion, which claims more adherents to-day than any other religion, was an offshoot of Judaism and that it assimilated much of the Jewish cosmogony into its theological conceptions. For this reason it is important to understand something about the Hebrews' astronomical knowledge at the period when some of their more important works were composed. The word "important" refers, of course, to their significance in so far as they influenced Christian theology; some have had a very much greater effect than others in this connection. As will be shown in subsequent chapters, the influence exerted by many of them on human thought and on social customs was profound.

## CHAPTER VIII

# ASTRONOMY OF THE MIDDLE AGES

For nearly five centuries after the death of Ptolemy, in the second century, there was very little advance in astronomy in Europe, and after that there was almost a complete blank. Interest in astronomy ceased, and several more centuries elapsed before a revival took place.

This did not apply to the East, where the Mohammedan conquerors were influenced by the people whom they had conquered. In the eighth century Bagdad became a great centre of activity—literary as well as scientific—and some of the Caliphs who were very interested in science did all that was possible to encourage its study. Among these may be noticed Al Mansur, who reigned from A.D. 754 to 775, and who collected learned men around him from both East and West. An Indian arrived at the Court in 772, and an Indian treatise on astronomy which he brought with him was translated into Arabic. It remained the standard work on astronomy for about half a century; but from what has been previously said about Indian astronomy it is very doubtful if this work contained much that was original. It was probably based on Greek writings. During the time of Al Mansur, and later, the Courts of the Caliphs had a body of men engaged in translating Greek writings into Arabic—not astronomical writings alone, but also medical treatises. Astronomy was the most favoured science, however, among the Arabs, partly because their ceremonial observances required practical astronomy. The Mohammedan calendar was a lunar one, and it was essential that various fasts and feasts should be observed at the correct times. In addition, Mohammedan worshippers, scattered about in various parts of the world, required to know the direction of Mecca, and welcomed the assistance that astronomy could give them. Astrology, too, was an important factor in encouraging the study of the stars, and no doubt the Caliphs encouraged the study of astronomy on account of its astrological application.

Harun al Rasid, who succeeded Al Mansur in 775, had the *Almagest* translated, and fresh translations were made on subsequent occasions until a final version appeared at the end of the ninth century. Other works on astronomy and mathematics were also translated, and by the end of the ninth century a considerable number of Greek books had been translated into Arabic—a fortunate matter for us, because it is to these translations that we owe our knowledge of these books, the original Greek texts of which have been lost.

An observatory was erected at Damascus during the time when the Caliphs lived there, and in 829 Al Mamun built another at Bagdad. He ordered his astronomers to verify Ptolemy's estimate of the size of the earth, and this was done by two separate measurements of portions of a meridian. Unfortunately they agreed with each other and also with Ptolemy's result—180,000 *stadia* for the circumference—and one is tempted to suspect that their measurements were not carried out with great accuracy. This does not imply that the Arab astronomers were careless; on the contrary, their careful observations very soon showed that the Greek astronomical tables were erroneous in places, and new tables were issued from time to time.

Tabit ben Korra, who made the final translation of the *Almagest*, is said to have discovered a variation in the amount of the precession of the equinoxes. His explanation was effected by means of a complicated mechanical system, and this caused considerable confusion in compiling astronomical tables for about six centuries. When we come to deal with Copernicus we shall see that he accepted this explanation, to which the name " trepidation " was given, but Tycho Brahe rejected the idea of the supposed irregularity in precession.

Al Battani, generally known by his Latin name Albategnius, was one of the greatest among the Arabian astronomers. His observations extended over the period 878–918, and during this time he did much valuable work. He obtained more accurate values of the obliquity of the ecliptic and of the precession of the equinoxes, and he produced improved tables of the positions of the sun and moon. One very important discovery by Albategnius

should be mentioned. The Greeks were aware that the sun was not always at the same distance from the earth; the name apogee was given to the point at which it was at the maximum distance, and the direction of this was given in the *Almagest*. From his observations Albategnius must have been aware that the apogee was slowly moving, though he did not state this fact quite definitely. Not only was he a good observer; he was a good mathematician as well; he introduced the use of sines into trigonometry and used some new formulæ for the solution of spherical triangles.

The last of the Bagdad astronomers was Abul Wafa (939–998), who wrote a large treatise on astronomy, known, like that of Ptolemy, as the *Almagest*, though its plan was quite different. It is possible that he discovered an inequality, known as the variation, in the motion of the moon. This is due to the varying amount of the sun's disturbing force, and is responsible for a maximum velocity of motion at new and full moon and a minimum velocity at the quarters. If Abul Wafa actually made this important discovery, it was completely ignored until it was announced by Tycho Brahe, who rediscovered it in the sixteenth century.

The Mohammedan dominions of Spain and northern Africa had a number of seats of education, such as Cordova, Toledo, Seville, and Morocco, and the *Toletan Tables* were produced late in the eleventh century under the direction of Arzachel. Some improvements in the astronomical instruments were effected at this time, and Ptolemy's views were subjected to destructive criticism, without, however, any constructive scheme being offered in place of them. When Spain began to throw off the Mohammedan yoke, interest in astronomy waned, and with the capture of Cordova and Seville, before the middle of the thirteenth century, Arab astronomy ceased.

When Hulagu Khan, a grandson of Genghis Khan, the Mongol conqueror, captured Bagdad in 1258, he encouraged the study of astronomy and appointed Nassir Eddin to take charge of a fine observatory at Meraga. The astronomers who worked under the superintendence of Nassir Eddin were provided with excellent instruments, and their *Ilkhanic Tables* contained a star catalogue, based partly on the results of their own observations, as well as

tables for computing planetary motions. They determined the value of the precession of the equinoxes to within about one second of arc of its true value, and it is interesting to note that Nassir Eddin discussed the supposed "trepidation" and was doubtful about its existence. With his assistants he translated a number of important Greek writings on astronomy and other subjects; among these treatises were the *Almagest*, some of the works of Archimedes, and Euclid's *Elements*. The death of Nassis Eddin in 1273 was, unfortunately, followed almost immediately by the collapse of the Meraga School which he had formed.

In 1420 Ulugh Begh, a grandson of Tamerlane, built an observatory at Samarcand, where he personally worked with a number of assistants. He published a star catalogue which covered almost the same field as that of Ptolemy, but the star-places were given with a high degree of precision, which suggests that the instruments were very good for the age in which he lived. It is true that errors of several minutes of arc frequently occurred, but this is not surprising when we consider the comparatively crude apparatus used in the Middle Ages. In 1449, when Ulugh Begh was murdered, Tartar astronomy came to an end.

Although neither the Arab nor the Tartar astronomers contributed much to theories or new ideas in astronomy, they were assiduous observers and also very skilful in computations. We are indebted to them for certain simplifications in mathematics, such as their introduction from India of our system of writing numbers, the practice of treating trigonometrical functions as algebraic quantities, etc. Europe also owes much to them for preserving the discoveries of the Greeks and for maintaining an interest in astronomy and other sciences at a time when the Western world had little use for such subjects. We sometimes forget, when we name some of the more prominent stars—Altair, Betelgeux, Vega, etc.—and use such common terms as "nadir," "zenith," and "almanack," that these words came direct from the Arabs.

Arab learning slowly percolated through Europe, and Pope Sylvester II, who occupied the Papal Chair from 999 to 1003, owed much of his scholarly equipment to the time he spent in

Spain near, or perhaps in, the Moorish dominions. He has been credited with making instruments of various kinds—including a brazen head which answered questions—but similar inventions are ascribed to Roger Bacon, Albertus Magnus, and others. Perhaps his invention of such magical instruments was responsible for the popular view that he had sold his soul to the Devil; though he seems to have excelled in making astrolabes, which can scarcely be considered magical instruments. Among the more enlightened Churchmen there was a quickened interest in scientific subjects, and early in the twelfth century Mohammedan influence began to assume importance.

At the beginning of that century a large number of treatises, philosophical and scientific, were translated from Arabic into Latin. These were not all original Arab works, some of them being Arabic translations of Greek books. In the early part of the next century several universities were founded in Europe, among which may be noticed that at Naples. The Emperor Frederick II had come into contact with Mohammedan learning when he was in Sicily, and in consequence he directed a number of scholars to make fresh translations from Arabic works.

Alfonso X of Leon and Castile did much to encourage astronomy, and under his superintendence the *Alfonsine Tables* were published in 1252. These were compiled by a number of astronomers working at Toledo; they superseded the *Toletan Tables* (see p. 77), and in certain respects were more accurate. In a book published by Alfonso, *Libros del Saber*, a compendium of astronomical knowledge, there is a diagram representing Mercury's orbit as an ellipse. It is generally believed that Kepler was the first to attempt to represent celestial motions by curves other than circles (see p. 101), but Alfonso had anticipated Kepler by more than three hundred years.

It will suffice to glance at the work of a few outstanding figures before Copernicus revolutionized men's conception of the universe. Up to that time none of the observations referred to during the Middle Ages was of great importance, with the exception perhaps of a few by Alfonso and his assistants. However, in Germany, during the fifteenth century, knowledge received

some additions which were symptomatic of a growing sense of independence and of an unwillingness to accept things merely on authority.

George Purbach, born in 1423, and one of his pupils, John Müller, known as Regiomontanus, were convinced, as a result of observations made at the University of Vienna, that astronomical reforms were overdue. They discovered serious inaccuracies in the *Alfonsine Tables*, Mars being about 2° from its predicted place and an eclipse of the moon taking place an hour later than the predicted time. After the capture of Constantinople by the Turks, in 1453, a Greek manuscript of the *Almagest* arrived at Rome, and Purbach and Regiomontanus were invited to go there to study it. Purbach died suddenly, and Regiomontanus went alone, remaining seven years in Italy, where he studied the *Almagest* in the original and also finished Purbach's *Epitome of Astronomy*, which he had begun in 1450, when he was appointed professor of astronomy and mathematics at the University of Vienna. After a short period spent in Vienna, and later in Hungary, he settled in Nürnberg, where one of the early printing-presses had been established. Bernard Walther, a wealthy citizen of that city, became a pupil of Regiomontanus, and supplied him with funds to carry on his work. Very accurate astronomical instruments were made and useful observations were carried out.

Regiomontanus later started a printing-press of his own, and in 1473 he brought out an edition of Purbach's book on planetary theory which showed the discrepancy between the views of Aristotle and those of Ptolemy. His press also issued almanacks which supplied useful information about movable feasts, eclipses, lunar phases, etc. The *Ephemerides*, issued by the same press, gave astronomical information for about thirty years in advance and contained data for determining latitude and longitude at sea by means of lunar distances.

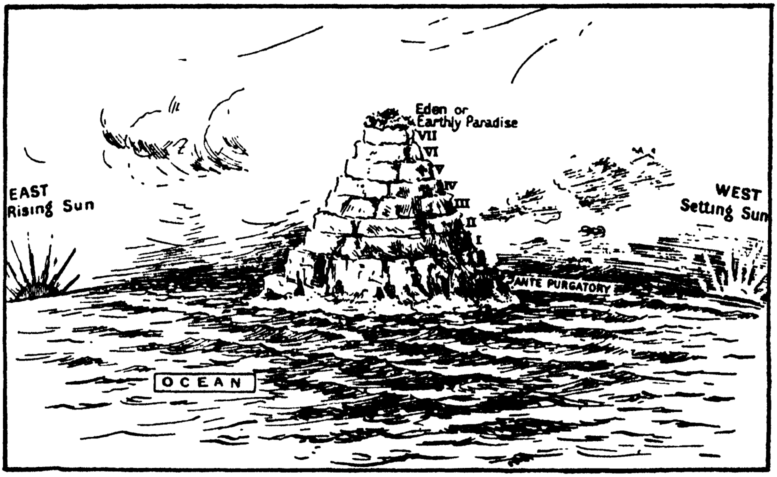
On the death of Regiomontanus, in 1476, Walther continued the work and made a series of useful observations. Although Ptolemy was aware of the phenomenon of refraction, to which he refers in his *Optics*, Walther was the first to allow for this in astronomical observations. After Walther's death the work at

the observatory continued, though there were no very worthy successors to Regiomontanus, and the Nürnberg astronomical school continued until the seventeenth century.

Among other names of note, reference may be made to Leonardo da Vinci (1452–1519), who was the first to explain the phenomenon of earth-shine—that is, the dim illumination seen over the surface of the moon when there is only a thin crescent shining. This is due to light reflected from the earth, illuminated by the sun. Jerome Frascator (1483–1543) and Peter Apian (1459–1552) not only wrote on astronomy, but also carried out important observations on a comet, noticing that the tail pointed away from the sun. John Fernel (1497–1558) determined the length of the earth's diameter and arrived at a result which was in error by less than one per cent. Little progress was made, however, by the work of those just mentioned, and astronomy was in an almost stationary state until Copernicus produced revolutionary results.

The growing interest in science at this time was stimulated by a number of important events, among which may be noticed the dispersal of Greek scholars over Europe when Constantinople fell to the Turks, in 1453. The discovery of America by Columbus, in 1492, had also a profound influence in stimulating inquiry and increasing interest in matters of knowledge, and the invention of printing, early in the fifteenth century, provided a powerful means for disseminating results of new discoveries. Authority was beginning to feel the effects of criticism and opposition. The Reformers questioned the authority of the Church, showing the inconsistencies between its doctrines and the teaching of the Bible, and, although they replaced the Church by the Bible in matters of authority, society was destined very soon to pass through a transition from the ecclesiastical to the secular ideal. A conflict between authorities had already arisen in astronomy, the divergencies between Ptolemy and Aristotle being obvious to those who dabbled in this science, and the discrepancies between astronomical tables, known more especially to the experts of the time, produced a feeling of dissatisfaction with the old basis of astronomy. Men questioned the old cosmogony with its mythological conception of hell, located by Dante within the earth,

and described by him as a funnel descending in nine diminishing whorls through the hemisphere until its central point is reached. It is not surprising that doubts arose about certain beliefs associated




[From *Dante and the Early Astronomers*, by M. A. Orr (Mrs. Evershed) (*by permission of the Author and Gall & Inglis*).

FIG. 9.—NORTHERN SLOPE OF THE MOUNTAIN OF PURGATORY, UP WHICH DANTE CLIMBED AFTER HIS VISIT TO THE INFERNO

with this region, that were in vogue in the Middle Ages. Events were favourable for a movement towards a new basis which would place astronomy on a firmer foundation than it had attained under the old traditions. The movement towards new ideas found its leader in a great astronomer, Nicholas Copernicus.

## CHAPTER IX

# COPERNICUS

THE age of Copernicus saw the transition from the astronomy of the ancients to the astronomy of the moderns, and in this transition there took place a complete change in men's conception of the heavenly bodies and of Creation itself. The revolution in thought was so great and fraught with such far-reaching consequences, which many even now do not fully appreciate, that we shall dwell at length on the life and activities in various spheres of this great original thinker, with the object of showing the reader what he really accomplished.

Nicholas Copernicus, the youngest of four children, was born on Feburary 17, 1473, at Thorn, a town which had belonged to the Hansa League and had come under the suzerainty of Poland a few years before his birth. His father had moved from Cracow to Thorn eleven years before Copernicus was born, and his mother, a sister of Lucas Waczenrode, Bishop of Ermland, came from a Polish family. It is fitting that Poland should abound in memorials of Copernicus, because, though he was of Slav ancestry, he was a Pole by birth. It is remarkable that German writers have claimed him as a German since the recognition of his greatness, but when his astronomical system was an object of ridicule, they always spoke of him as a Pole. Perhaps it is equally remarkable that no statue is erected to his memory in Germany, in spite of the claims that he was a German.

On the death of his father, when Copernicus was ten years old, his uncle, the Bishop of Ermland, took care of him, and when he had finished at the School at Thorn, which he attended until he was eighteen, he went to the University of Cracow. At that period the University of Cracow attracted eminent humanists and students from all parts of Europe, and not only was the city noted for its university, but it was also the capital of a great State and the centre of economic activity. Both its culture and wealth exercised a considerable influence on the mental development of Copernicus, as he himself frequently admits.

During his five years at Cracow, astronomy was still taught almost entirely from the mediæval standpoint. It was associated with astrology and was bound up with Aristotelian physics, but on the practical side it was used for the determination of dates and the arrangement of the Church's calendar. Copernicus, who was rather reserved in his manner, had his mind awakened, and he thirsted for knowledge—so much so, indeed, that he is said to have filled his shelves with books. His uncle hoped that a brilliant career in the Church lay before his nephew; Copernicus had the same ambition, so it is not surprising that when he left Cracow, in 1496, he went to Bologna to study Canon Law. After three years at Bologna he obtained the degree of Master of Arts, and though his interests were very diverse, his chief work centred round astronomical phenomena. Novarra of Ferrara was the professor of astronomy at that time, and Copernicus collaborated with him in measuring stellar altitudes and calculating the parallax of the moon. His observations then led him to doubt the lunar theory of Ptolemy, and considerations of the moon's motion later suggested to him an argument in favour of the earth's motion. In 1500 he delivered a course of lectures at Rome on astronomy and mathematics, and it is probable that even at that time he pointed out certain flaws in the Ptolemaic system—over forty years before the appearance of his monumental work.

In the early part of 1501 he returned to Poland to be installed as Canon of Warmia, but as he had no intention of settling down in his native country at that time he obtained permission to return to Italy for further studies. The cathedral chapter provided funds for him on condition that he studied medicine at the University of Padua, and for four years he devoted himself to the study of medicine and philosophy. These were not his only interests, however, and it appears that classical literature, Aristotle's metaphysics, philology, and—above all—astronomical research, claimed his attention. In 1503 he was awarded a Doctorate of Canon Law at Ferrara, and the same year he returned to Poland to embark on his clerical duties at Ermland.

After his return to Poland, Copernicus took up the practice of medicine, not only treating his fellow-canons, but also being most

assiduous in attending the poor. It is certain, from the reminiscences and anecdotes, and also from his correspondence, which has been preserved, that he must have had a very extensive practice. His friends spoke of him as a "saviour," always ready to answer any call.

Copernicus attained some proficiency in languages, and published a translation from Greek into Latin of the poems of Theophylactus Simocatta. He had also some artistic skill, and tradition tells of his technical and engineering ability; he is said to have constructed a pump at Frauenburg for raising water to a great height. His treatise on money attracted much attention in Europe in the latter half of the nineteenth century, as he formulated the law, later known as Gresham's Law, that bad money, if recognized as legal tender, will drive out good money. In addition he showed the necessity for making the ratio of the values of gold and silver coins depend on the ratio of the values of the two metals. While Copernicus received marks of recognition on account of his diversity of attainments, it was in his capacity as an astronomer that he reached the pinnacle of fame.

Bishop Waczenrode was a stern and despotic man who ruled Warmia as though it were a separate State of the Church. From the time of his nephew's return to Poland until the Bishop's death in 1512, Copernicus was closely associated with various political activities. Although these occupied a large part of his time, he still found opportunity for his celestial researches, and in 1509 he produced his *Nicolai Copernici de hypothesibus motuum coelestium a se constitutis commentariolus*. This gave a short account of his new system. All the motions of the planets can be explained on the supposition that they revolve round the sun, which is immovable; and the centre of the earth is not the centre of the universe: it is only the centre of gravity of the earth and the centre of the moon's orbit.

The circulation of this work among the friends of Copernicus roused a certain amount of opposition against such novel teaching. It was not until 1517, when changes in the political situation released him from various State duties, that he was able to start on his great work, *De Revolutionibus orbium coelestium*, and it is

believed that the first draft in writing was not finished until 1530. His Polish friends were aware of his views, as was his patron, Bishop Tideman Gise, of Chelmno, who urged him to publish his theories; but the general public knew little or nothing about these views. In 1533 Pope Clement VII received an account of the theories of Copernicus, but, while persecution by the Church was to be feared, what Copernicus really dreaded was ridicule, as he had a very sensitive nature and shrank from the laughter that might be provoked among those who would regard as absurd the notion of a "stationary" earth moving. In 1531 he had actually been satirized on the stage near Frauenburg, and even Martin Luther went out of his way to be aggressive towards him, describing him as the "new astrologer . . . the fool who wanted to overturn the whole science of astronomy." It is certain that Copernicus felt these remarks very acutely, and indeed in his dedicatory letter to the Pope, prefaced to *De Revolutionibus*, he makes it clear that this consideration had prevented him from publishing his views previously.

It is a remarkable reflection that Copernicus's work might have remained unpublished had it not been for the influence of Joachim Retyk, generally known as Rheticus, a mathematician from Wittenberg. Having heard about the views of Copernicus, he came to Frayenburg in 1539, and was very soon convinced of the truth of the new views. In 1542, after much difficulty, he obtained a copy of the manuscript from Copernicus, whom he called his teacher, and took it to Wittenberg in the hope of inducing someone to print it there. Unfortunately the Lutheran University town was not a very favourable place for the new views to take root, and both Luther and Melanchthon opposed the publication. Melanchthon even appealed to the magistrates to restrain the levity of one who moved the earth and made the sun stand still. Rheticus, though discouraged, did not despair, and he succeeded in procuring the publication at Wittenberg of Copernicus's *Trigonometry*, which included chapters 12–14 of *De Revolutionibus*. After this a Nuremberg bookseller named Petreius decided that the publication of the whole work was a financially sound proposition, but before it was published a serious interpola-

tion was effected by the editor, Andreas Osiander, a Lutheran theologian. Omitting Copernicus's original preface, he replaced it by an anonymous one of his own, representing the opinions of Copernicus as mere hypotheses, not necessarily based on any physical reality.

Although Osiander was deceitful in the matter of his anonymous preface, he may have had good motives for his action, because he thought it advisable to disarm prejudice and also to circumvent religious scruples. Nevertheless, his prefatory note had a bad effect so far as Copernicus was concerned, because it created a widespread impression that he had formulated his theory merely as a mathematical device to explain more simply the motions of the heavenly bodies, but that he did not believe it corresponded to reality. In his own preface, addressed to Pope Paul III, he gave his reasons for publishing the book, and quite fearlessly stated that he regarded the idea of the immobility and central position of the earth as absurd. He pointed out the stupidity of those who held such views, and scorned those who, devoid of any mathematical knowledge, distorted passages in the Holy Scriptures. This in itself proves conclusively that Copernicus did not delay the publication of his work because he dreaded persecution by the Church. As we shall see later, however, the Church reacted against his doctrine many years afterwards, because it saw in it certain religious implications which it considered dangerous.

In the early spring of 1543 the *editio princeps*, prepared for the outlook of the leading German intellectuals by the anonymous preface, made its appearance, and soon afterwards Copernicus died at Frauenburg, on May 24. It is said—but the story lacks confirmation—that he laid his fingers on his life's work when sight and touch were failing him.

Prior to the publication of *De Revolutionibus*, the Aristotelian system of cosmology was the one most generally accepted. The planets were supposed to be attached to a number of material spheres, the earth being the centre of the system. The stars were embedded in another sphere of finite radius, of which the earth was also the centre, and this sphere—the *primum mobile*—

rotated once in twenty-four hours. The spheres containing the planets rotated in a direction opposite to the *primum mobile*, but the superior force of the latter dragged them along in its direction of rotation. As Saturn was nearest to the sphere containing the stars (no planets outside Saturn were then known) it had the greatest difficulty in overcoming the force of the stellar sphere and hence took a long time to complete a rotation. On the other hand, the Moon, which was nearest to the centre, had the least difficulty in overcoming this force, and hence took the least time. Although all the spheres were concentric with the earth, their axes were not coincident, nor were they necessarily constant in direction. A total of 55 spheres was necessary to explain the observed motions of the heavenly bodies.

It has been shown (see p. 44) that Eudoxus originally designed the system of concentric spheres, which accounted fairly well for the motions of the stars and planets for a short period of time. The results of observations over long periods, however, showed that the spheres were inadequate to explain the motions of the heavenly bodies, so new devices became necessary. When Ptolemy summarized the main facts and principles of astronomy in his *Almagest*, more than two-and-a-half centuries after the days of Eudoxus, his system had little resemblance to any previously accepted. It should be said that Ptolemy regarded his system as a mere calculating device. To describe it in detail would be both tedious and unprofitable, as its complications are more likely to confuse than to enlighten the reader. We must now summarize briefly the achievements of Copernicus.

While some of the ancient astronomers had taught that the earth was in motion, their views had been offered more as a philosophical speculation than as a statement of fact. None of them had followed out the implications of this conception, nor had they developed it into a system which could explain the complicated motions of the planets. By placing the sun at the centre and assigning a diurnal rotation and an annual revolution to the earth, Copernicus brought about a profound change of outlook. The Arabian astronomers had postulated a phenomenon of " trepidation," which they supposed to be an oscillation

of the equinoxes backwards and forwards, producing fluctuations in the value of the precession of the equinoxes. Copernicus accounted for the "trepidation" by assigning two librations or swaying movements to the earth's axis, so that, in addition to its movements of rotation and revolution, the earth had a wobbling motion of its axis. The first two motions did not explain everything satisfactorily, and he had to appeal to the Ptolemaic system of eccentric and epicyclic circles to account for the motions of the bodies in the solar system.

It is important to notice the title of Copernicus's work; the word *orbium* does not mean stars or planets, but spheres or circles, and it was the motion of the circles that was real even to Copernicus. He succeeded in reducing the number of circles to thirty-fôur, and so far introduced some simplification in detail, though none in method. It was only after accurate observations by Tycho Brahe (who was born about three years after the death of Copernicus), followed by the computations of Kepler, that it was shown that the orbits of the planets were not circles but ellipses. Nevertheless, the tables based on the calculations of Copernicus, which Reinhold constructed in 1551 (known as the "Prutenic Tables"), were superior to the *Alphonsine Tables*, published in 1272, and were in use until the appearance of Kepler's *Rudolphine Tables* in 1627.

From the practical point of view, the great advantage of the Copernican system was the simple explanation it afforded of the retrograde motions of the planets. These motions were mere appearances, due to the revolution of the earth around the sun—in fact a parallactic motion. Copernicus realized that the stars should show an appreciable parallax when the earth was on opposite sides of the sun in its orbital motion, but as no parallax was observable, he concluded that the stars must be very far away from the earth. Strange to say, herein lay the possibilities of a conflict with the Church; indeed, on this very point the Church condemned the Copernican system seventy-three years after the publication of the *De Revolutionibus*.

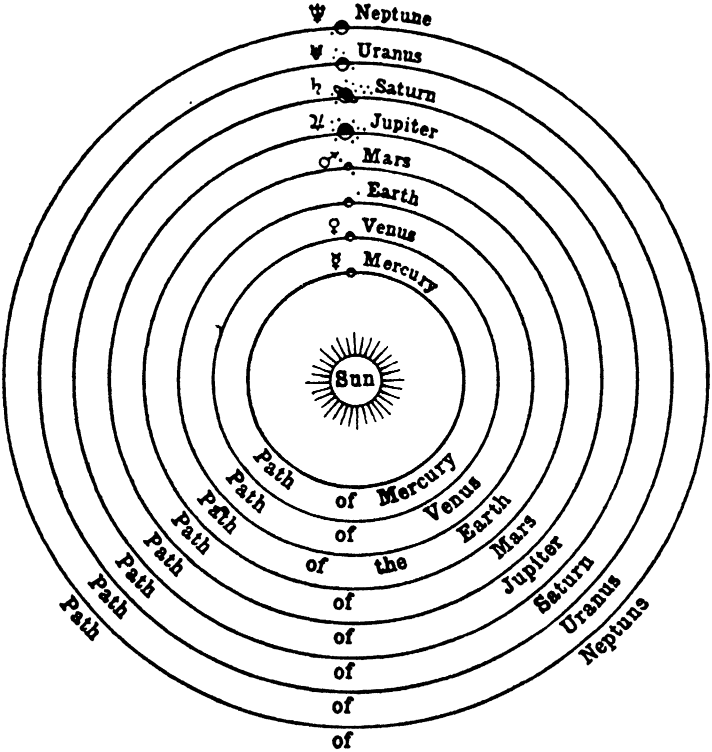
In the Ptolemaic system the sphere of the fixed stars was located just beyond that of Saturn. As we have seen, Copernicus con-

cluded, and rightly, that because the stars showed no parallax, there must be a vast space between them and Saturn. It was a simple step from this view to the view that the universe was infinite, and though Copernicus had not taken this step himself, he had removed the great obstacle to it. When it was believed that the stars were revolving round the earth it was natural to postulate their proximity to us, because if they were very far off they would require a high speed to complete their course in 24 hours. If they were at an infinite distance their speed would necessarily be infinite—which would be an absurdity. So, when Copernicus transferred the daily motion to the earth there seemed no fundamental objection to an infinite universe. The Church, however, was not prepared to accept an infinite material universe, with no abode available for the blessed beyond the outermost sphere. This may seem a trivial matter to us to-day, but it was not trivial in the days of Copernicus. In 1616 *De Revolutionibus* was placed on the *Index* and declared heretical. The book was not absolutely forbidden, however. It was permissible to read it if all passages referring to the motions of the earth were altered to assert that this view was false and was introduced merely as a hypothesis to simplify calculations. The book remained on the Papal *Index* until 1835.

In the days of Copernicus there was no possibility of providing observational proof of the motion of the earth around the sun, and it was not until 1729, when Bradley's discovery of aberration was announced in the *Philosophical Transactions*, that observational evidence was forthcoming. Aberration of light is the phenomenon in virtue of which the apparent places of the stars as viewed from the earth differ from their true places. It is due to the fact that the velocity of light is finite; hence, combining this finite velocity (about 186,000 miles a second) with the orbital velocity of the earth (18½ miles a second), in accordance with the well-known principle of the parallelogram of velocities, the rays of light from a star appear from a direction different from that which they would follow if the earth were not in motion. Additional evidence was provided more than a century later when Bessel in 1838, Henderson in 1839, and Struve in 1840, announced

that they had detected the parallaxes of fixed stars. Long before the observational evidence in any form was forthcoming, however, the Copernican system had been accepted.

Looking back to-day over four hundred years of astronomical




[From *Religion in Science and Civilization*, by Sir Richard Gregory (*by permission of Macmillan & Co., Ltd.*).

FIG. 10.—ORDER OF THE PLANETS IN RELATION TO THE SUN, AS REPRESENTED IN THE COPERNICAN SYSTEM.

progress the work of Copernicus must be recognized as a great landmark in scientific history. He made possible the birth of a new world, for without his labours the work of Kepler and Newton would have been impossible and the whole course of dynamical astronomy might have been delayed for centuries. Riccioli,

although condemning the Copernican doctrine, pays a tribute to the greatness of Copernicus when he says: "The greatness of Copernicus has never been sufficiently appreciated nor will it be—that man who accomplished what no astronomer before him had scarcely been able to suggest without an insane machinery of spheres, for by a triple motion of the earth he abolished epicycles and eccentrics. What before so many Atlases could not support, this one Hercules had dared to carry. Would that he had kept himself within the limits of his hypothesis!"

Copernicus's work was read after his death, but at first the theory of the earth's movement aroused little interest. Agreement with observation was looked for, and to obtain approximate agreement between theory and observation it was not necessary to suppose that the earth moved, because the movement of the sun and planets round the earth would fit in with observed phenomena. The attitude of the Church in erasing certain passages which seemed contrary to orthodox doctrine also retarded the acceptance of the heliocentric view. By the end of the sixteenth century the Church was fully alive to the dangers inherent in the Copernican system, and about 1591 Giordano Bruno was imprisoned and in 1593 brought to Rome on account of his beliefs. An adherent of Copernicus, he taught certain theories based on the belief in the infinity of the cosmos and the plurality of worlds, and after seven years' confinement he was burned at the stake, on February 9, 1600.

Less than four years after the death of Copernicus, Tycho Brahe was born. Largely through his work the Copernican doctrine was firmly established.

## CHAPTER X

# TYCHO BRAHE

TYCHO BRAHE was born on December 14, 1546, at Knudstorp, in the south of Sweden, which at that time was Danish territory. He came from an aristocratic family, and his father was a Privy Councillor and also lieutenant of different counties at various times. Although Tycho was brought up by an uncle, Jörgen Brahe, this arrangement was not due to any pecuniary circumstances in his family, but to a promise made by Tycho's father to hand over a son, if such were born, to Jörgen, who was childless. When Tycho was born, his uncle expected the fulfilment of the promise, but as his parents refused to recognize their obligation, Jörgen made a raid on the house when Tycho was about a year old and carried him off. The parents submitted to this indignity, and it does not appear that they took any steps to recover their son.

After spending his boyhood at Tostrum, in his uncle's home, Tycho entered the University of Copenhagen when he was just over twelve years old. As both his father and uncle intended that he should become a statesman, he studied rhetoric and philosophy especially, but when he was fourteen years old an event occurred which probably altered his whole career. On August 21, 1560, there was an eclipse of the sun, which took place very close to the predicted time. Tycho was much impressed with the fulfilment of the prediction, and he records that it struck him "as something divine that men could know the motions of the stars so accurately that they could long before foretell their places and relative positions." For three years following the eclipse his attention was taken up chiefly with mathematics and astronomy.

When Tycho left Copenhagen University his uncle decided to send him to Leipzig to study law, and Anders Sorensen Vedel was selected to accompany him as tutor. While he was at Leipzig his interest in astronomy was so intense that Vedel realized the uselessness of attempting to divert him from a subject which so

enthralled him. Instead of studying law, therefore, Tycho was left free to devote his time to scientific subjects.

A conjunction of Jupiter and Saturn took place while he was at Leipzig, and on consulting two different sets of tables—the *Alphonsine Tables* compiled by the direction of Alphonso X of Castile on the basis of the Ptolemaic system, and the *Prutenic Tables* drawn up by Reinhold, a disciple of Copernicus and dedicated to the Duke of Prussia—Tycho concluded that the *Alphonsine Tables* were a month in error. Although the tables based on the Copernican system were only a few days in error, Tycho was not attracted by the system, and indeed he remained a convinced opponent of Copernicus's views throughout his life. It was fortunate that he adopted the unusually sane view, for the time, that it was necessary to interrogate the heavens to decide which system was correct. Observational work, and not mere speculation, was essential, and Tycho devoted himself to this task.

In May, 1565, Tycho returned to Denmark, but as his uncle died soon afterwards and his family looked askance at his astronomical pursuits, he decided to leave Denmark for further study. He went to Wittenberg, and after a few months he repaired to the University of Rostock—as the plague had broken out at Wittenberg—and there he made a large number of astronomical observations. Three years later King Frederick II promised to give him the first canonry at the Cathedral of Roskilde, in Seeland—a promise which was later fulfilled. These canonries were not abolished after the Reformation, but were secularized, and learned men engaged on some form of research or on other pursuits were able to derive an income from them. In 1569 he went to Augsburg, and for nearly two years was occupied in chemical and astronomical research. On his return to Denmark in 1571, on account of his father's illness, which proved fatal, he inherited half the property, and his maternal uncle, Steno Belle, provided him with a convenient place at his castle, near Knudstorp, for making observations and also building a laboratory. The appearance of Nova Cassiopeiæ, in 1572, was an event which made a profound impression on Tycho, chiefly because it must have

given a shock to the defenders of the Aristotelian philosophy. Tycho writes as follows about the phenomenon :—

> All philosophers agree . . . that in the ethereal region of the celestial world no change in the way either of generation or corruption takes place; but that the heavens and the celestial bodies in the heavens are without increase or diminution, and that they undergo no alteration either in number or in size or in light or in any other respect; that they always remain the same, like unto themselves in all respects, no years wearing them away.

Tycho was unable to find a parallax for the star, and hence concluded that it could not be located in any of the lower spheres. He announced his views about the body in his book *De Nova Stella*, published in 1573, in which he expressed the opinion that it was a star, shining in the firmament, which had never been seen before in any age since the beginning of the world.

Tycho's marriage to a peasant girl caused some trouble with his aristocratic relatives, and in 1575 he again left Denmark, visiting various places in Germany. When he returned to Denmark King Frederick II offered him the small island of Hveen, in the Sound, where he could pursue his astronomical work, and conferred on him not only the promised canonry, but also a pension. Tycho erected an observatory on the island, and there he worked for twenty years at his astronomical observations.

Soon after he had settled at his observatory, which he named Uraniborg—the city of the heavens—a bright comet appeared, and Tycho was able to observe it for two months. Although his instruments were then rather crude, they were sufficiently accurate to measure the parallax of the comet if it were between the earth and moon, but as no parallax could be detected, the comet could not be of the sublunary nature then attributed to all comets. (To determine the parallax, observations were made simultaneously from two different places.) This was a shock to Tycho, who accepted the current belief regarding the distances of comets from the earth. But it was chiefly in his planetary observations that his fame as an astronomer rests.

Tycho knew that the only method for settling the question of the system of the universe was by amassing planetary observations. He rejected the Ptolemaic system very early in his career, and he would probably have accepted the Copernican view if only he had been able to overcome certain theological difficulties. It must be remembered that Tycho had largely the outlook of his time, in spite of the fact that he displayed a pioneering spirit in observational astronomy. He believed in astrology, and even went so far as to work out horoscopes for his friends. He weighed the evidence for and against the Copernican doctrine and concluded that the balance was against it. He believed that a stone falling from a high tower would fall a long way from its foot if the earth rotated, and an insuperable difficulty to him was the absence of an annual parallax in the stars. He was unwilling to place the stars as far off as Copernicus had done, and he believed that the star sphere was less than 60 million miles distant.

Tycho recognized the great advantages of the Copernican system in providing more accurate data for planetary positions, and he was anxious to find another system which would possess these advantages and yet not violate the authority of Scripture by postulating a moving earth. In 1577, in his book on a comet of that year, he promulgated the "Tychonic system," which retained the earth as the centre of the universe and also of the sun and moon and the sphere of stars. The earth, however, is not the centre of the orbit of the five planets—Mercury, Venus, Mars, Jupiter and Saturn. The sun is their centre, and the radii of the orbits of Mercury and Venus are smaller than the sun's orbit. The system accounted for irregularities in the planetary motions, which were explained on the Ptolemaic system by means of epicycles, but it had a short history and was soon discarded as a result of the advance of astronomy.

In spite of all his observations Tycho established no system of astronomy, but this does not imply that his labours were in vain. Far from it. As we shall see later, his observational results were invaluable in the hands of Kepler.

After the death of King Frederick II, in 1588, difficulties arose between Tycho and the Government, and in 1597 he left Den-

mark for Germany, as some of his income had been taken from him. However, he found a friend in the Emperor Rudolf II, who invited him to become his imperial mathematician, with residence at Benatky. Installing his instruments at the castle of Benatky, Tycho took up his old work again and then searched for an assistant. Fortunately for the progress of astronomy his choice fell on Johann Kepler, who had been exiled from Styria because of his adherence to Protestantism. In 1600 the Emperor invited Tycho to live at Prague, and in October 1601 Tycho was suddenly taken ill while at supper in the house of the magnate of Prague, and died on the 24th of the same month. While he was on his death-bed he begged Kepler to finish his new tables of planetary motions, which were to be called the *Rudolphine Tables*, in honour of the Emperor. He added the hope that in this way Kepler would prove the truth of the Tychonic system. Within eight years Kepler had demonstrated its falsity.

CHAPTER XI

# JOHANN KEPLER

JOHANN KEPLER, who was born on December 27, 1571, at Weil der Stadt, in Würtemberg, came from a very unpromising stock. His father, Heinrich Kepler, was a mercenary of the Duke of Alva and had previously squandered most of his share of the family fortune. His wife was an illiterate, whom Heinrich abandoned on several occasions, and when Johann was only five she followed in the wake of the Army, leaving the children behind. Johann was fostered by his grandfather at Leonberg, where an attack of smallpox left him with crippled hands and impaired sight. He attended a school when he was six, but the following year his parents returned, and opened a tavern at Elmindingen, where Johann and his two younger brothers were obliged to work. Perhaps it was fortunate for the progress of astronomy that Johann was too frail to endure great hardship, because he was sent to a school later, and when he was nearly fifteen he was admitted to a higher school at Maulbronn, where he was prepared for the University of Tübingen. As Protestant Germany provided considerable facilities for a good education in those days, Johann, who showed great promise, made rapid progress, and at seventeen he received the bachelor's degree at Tübingen University. He remained at the University mainly to study theology, but he attended lectures on astronomy, delivered by Michael Maestlin, professor of mathematics, and received the degree of master when he was only twenty.

After receiving his master's degree he remained for some time at Tübingen and sought an appointment, and in 1594 he obtained the position of lecturer in mathematics and astronomy in the University of Gratz, in Styria. There seems to have been no difficulty about a Protestant securing such a position. Although the ruler, the Archduke Charles of Austria, was a very zealous Roman Catholic, he was extremely tolerant. At this period

Kepler was interested in astronomy but not really enthusiastic, his main interest being philosophy. His lectures were not well attended, and on Maestlin's suggestion he devoted more time to the study of astronomy.

One of Kepler's duties at Gratz was the preparation of the yearly almanac, and, as was the custom, he included astrological predictions. Perhaps it was unfortunate that some of them came true, because, though this success increased the sales, it aroused the suspicion in later years that Kepler was not sincere in his astrological labours, which became more lucrative. He defended his belief in astrology in a work *De Fundamentis Astrologiæ Certioribus*, and it should be pointed out, in justice to Kepler, that there was a revival of belief in astrology in the sixteenth century and also a fairly wide acceptance of the cult in the century following.

Kepler was strongly attracted by the Copernican system of astronomy and he defended it vigorously in the first chapter of his great work, *Prodromus Dissertationum Cosmographicarum Continens Mysterium Cosmographicum*, published in 1596. His object in producing this work, however, was not to support the Copernican system, but to set forth his own greatest astronomical discovery. In the preface he says: " There were three things in particular—namely, the number, distances, and motions of the heavenly bodies—as to which I searched zealously for reasons why they were as they were and not otherwise."

Placing the sun at the centre, he attempted to find out the mystery connected with the number of the spheres and their distances, and also to discover the mind of the great designer who, he believed, created the universe on mathematical principles. In his attempt to find a simple ratio between the sizes of the principal circles of the epicyclic orbits he was led to insert an unseen planet between Mars and Jupiter, and another between Mercury and Venus. When this plan failed he tried trigonometric ratios, with no better success; and then, on astrological principles, he tried geometry, which was equally unsuccessful. Finally, he tried his extraordinary theory of the five regular solids.

In the introduction to his account of this novel idea he says:—

> I undertake to prove that God, in creating the universe and regulating the order of the cosmos, had in view the five regular bodies of geometry as known since the days of Pythagoras and Plato, and that he has fixed, according to those dimensions, the number of heavens, their proportions, and the relations of their movements.

The scheme is summarized in his own words as follows:—

> The earth is the sphere, the measure of all; round it describe a dodecahedron; the sphere including this will be Mars. Round Mars describe a tetrahedron; the sphere including this will be Jupiter. Describe a cube round Jupiter; the sphere including this will be Saturn. Now inscribe in the earth an icosahedron, the sphere inscribed in it will be Venus; inscribe an octahedron in Venus; the circle inscribed in it will be Mercury.

In a letter he mentions the rapture which accompanied his discovery, and he describes how he shunned no toil of reckoning until he could find out whether his hypothesis would agree with the orbits of Copernicus. When he had checked his theory by the best available data the agreement was not so close as he desired, and he undertook to improve the data to fit the "harmony" which he had established. The corrections were sometimes large, but there was very little improvement in agreement between the theory and the amended data.

Kepler's task in dealing with Mars was to get an orbit that would be in agreement with Tycho's observations, and he devised many schemes to effect reconciliation—but without success. Finally he elaborated a geometrical scheme which represented the observations on the assumption that Tycho's observations were in error to the extent of eight minutes of arc; but, strong as the temptation may have been to assume such an error on Tycho's part, Kepler rejected the assumption. It then occurred to him to try some other orbit than a circle—a very bold and independent step in those days, because since the time of Plato the principle of uniform circular motion for perfect celestial bodies had been

unquestioned. In 1603, in a letter to Fabricius, Kepler had told him that the orbit of Mars was oval, and he was led to try the ellipse, the simplest of oval curves. When the sun was placed at a focus of the ellipse the results agreed with the observations of Tycho, and Kepler had reached his first law, that a planet moves in an orbit which is an ellipse, the sun being in one focus.

His next step was to attack the problem of the variation of the planet's rate of motion at different parts of its orbit. He was aware of the fact that Mars moved faster when near the sun, and slower when at a greater distance from it, and finally he formulated his second law, that the area swept out by the line joining the sun and Mars was proportional to the time. Although these two laws were based solely on observations of Mars, Kepler's sense of harmony recognized that they must be applicable to the other planets also. He was assiduous in his investigations of the motions of the other planets, and in 1619 he produced *Harmonicès Mundi*, which contained his statement of his third law of planetary motion: "The squares of the periods of revolution are proportional to the cubes of the mean distances from the sun." This was merely one of many harmonic relations formulated as a result of his mystical speculations.

Kepler's marriage, in 1597, to a widow who had been divorced brought many difficulties, and the following year the Archduke Ferdinand II of Austria, an ardent Roman Catholic, vowed that he would exterminate heresy from his domain. All Protestant preachers and teachers were ordered to leave Styria, and Kepler fled to Hungary; but through the influence of the Jesuits he was allowed to return. His joy, however, was of short duration; he was again banished, and allowed forty-five days' grace to dispose of his wife's property. It was at this time that Tycho Brahe urged Kepler to come to him at Prague—an offer which Kepler did not at first accept, as he was aware of Tycho's violent temper and arrogant manner; but when he paid a visit to Tycho, in 1600, the inducements offered to Kepler decided him in his choice. He was presented to the Emperor Rudolph, who appointed him Imperial Mathematician to carry on computations with Tycho for the *Rudolphine Tables* (see end of previous chapter).

The death of Tycho placed very valuable observational data in the hands of Kepler, and for nearly thirty years he tested his speculations by means of this inheritance. He was not an observer himself, but he knew how to make good use of the observations of others, and Tycho's observations of Mars in particular were of the utmost importance for Kepler's purpose. It must not be assumed that he was free from financial worry during this time. On the contrary, not only was his salary small, but it was paid very irregularly, and he was forced to supplement his income by casting horoscopes. One of these was for the Emperor himself.

We shall now consider the first part of Kepler's great work on Mars, which was responsible for the first and second laws of planetary motion. These are set forth in his book, *Astronomia Nova seu Commentaria de Motibus Stellæ Martis*, published at Prague in 1609.

The most whimsical ideas follow, chapter after chapter, in utterly fantastic succession. Thus in the last chapter, devoted to planetary harmony, he starts with Saturn as the *basso profundo* and proceeds to enumerate the parts played by the other planets—Jupiter the bass, Mars the tenor, the earth the contralto, Venus the soprano, and Mercury the falsetto. The plaintive melody of the earth gave the notes Mi, Fa, Mi; and here is an explanation of terrestrial misery, *Mi*, and famine, *Fa*. Although such vagaries seem to be more akin to the rhapsodies of the religious mystic than to the utterances of the cold and calculating astronomer, we must give Kepler credit for his three laws, which are of fundamental importance, and which have exercised considerable influence on the advancement of astronomy. Kepler had a consciousness of a mystical union with the Creator of the harmonies of the universe, and some of his rhapsodies unite a deep religious experience with high scientific attainment.

The *Epitome Astronomicæ Copernicæ* appeared in parts in 1618, 1620, and 1621, and was immediately placed on the *Index* of prohibited works because by that time the Church realized the dangers to the tenets presented by the new doctrine. This work covered the whole field of astronomy. The first two laws of

motion were applied to the other planets and also to the moon; in addition, the third law was extended to Jupiter's system of satellites discovered by Galileo in 1610. It must not be supposed that Kepler's work was free from errors. Many of his conclusions were utterly erroneous; but this does not detract from the magnitude and far-reaching consequences of some of his discoveries. Although he improved a number of the astronomical constants, the amended results were far from the truth. Thus, before his time the distance of the sun from the earth was believed to be 1,200 terrestrial radii, or less than 5 million miles. Kepler increased this threefold, but this still gave only about one-seventh of the true value. He assumed that the distance of Saturn was a mean proportion between the radius of the sun and the distance of the stars, and he obtained for stellar distances 60 million times the earth's radius—a result about one-hundredth part of the distance to the nearest star. On the other hand he gave a correct explanation of eclipses and also of the method for computing them, and he attributed the ruddy appearance of the eclipsed moon to atmospheric refraction. He suggested that the corona, seen during total eclipses, was a solar appendage—a view which was not accepted until two centuries later.

His treatise on comets, published in 1619, was not of great value. While he accepted Tycho's view that comets were not sublunary, he believed that their motion was rectilinear. He thought that they existed in large numbers and that they exercised baneful influences on the affairs of men. He made a shrewd conjecture as to the reason why comets' tails point away from the sun, his suggestion being that the rays of the sun penetrate the body of the comet and drive off some of the material—an anticipation, in a crude form, of modern views on the subject.

Kepler concentrated on the completion of the Imperial Tables, but unfortunately various circumstances—including political and religious difficulties and lack of funds—delayed the work. In 1627 the *Rudolphine Tables* were finished, the culmination of the observational work of Tycho Brahe and of the theoretical work of Kepler over a quarter of a century. Tables of logarithms and of refraction were appended and also a catalogue of 1,005 stars, of

which 777 had been observed by Tycho. The use of occultations of stars by the moon to determine differences of longitude was proposed by Kepler, and he was one of the first to use logarithms. In 1620 he wrote a letter to Napier, unaware of the fact that Napier had died three years previously.

Kepler's latter years were not very happy ones. His mother was charged with sorcery and attempted poisoning, and it was only through his intervention for clemency that she escaped capital punishment. In 1626 he was driven from his chair at Linz by religious persecution, and resided at Ulm for three years, though he still retained the office of Imperial Mathematician. In 1629 the Duke of Friedland secured for him a rather unattractive chair at the University of Rostock, but as his salary from the Imperial Treasury was very much in arrears he set out on horseback the following year for Regensburg to plead his case before the Diet, then in session. Soon after his arrival he died—on November 15, 1930—as a result of a severe chill.

Kepler was not an observer, as we gather from his own confession. For observations "his eye was dull, and for mechanical operations his hand was awkward." He attained fame as an astronomer almost entirely through his laws of planetary motion, and it must not be forgotten that these were mere empirical laws, not based on any dynamical principles. Argo's tribute to Kepler is worth quoting: "The laws of Kepler are the solid and unshakable foundation of modern astronomy, the eternal and unchangeable rule of the motion of celestial bodies in space. The glory of Kepler is written in the heavens; the advances of science can neither diminish nor darken it, and the planets by the ever-constant succession of their regular movements will proclaim it from age to age."

## CHAPTER XII

# GALILEO DE GALILEI

GALILEO DE GALILEI was born at Pisa on February 15, 1564—more than seven years earlier than Kepler; but as their methods and also their contributions to astronomy were very different, it is unnecessary to observe chronological order in dealing with them. Galileo came of an ancient stock, and his father, an impoverished member of a Florentine family, was a cloth merchant, but he was a man of many gifts, including musical ability. He was also a good mathematician and a classical scholar. Galileo received his early education in Pisa, and when he was twelve he was sent to the monastery school of Vallombrosa. His father intended that he should take up commerce, and when the boy showed some inclinations towards the monastic life he removed him from Vallombrosa at the age of fifteen. Galileo had been experimenting with toy machines and had also shown some skill in painting and drawing, so his father, recognizing that his talents lay in directions other than commerce, sent him to the University of Pisa in 1581. He was enrolled as a student of medicine when he was seventeen; but it soon became evident that he had no particular desire for medicine as a career, his chief interests being in experimental science and mathematics. He gained notoriety for his controversial nature, showing a great unwillingness to accept the traditionalism of his teachers without evidence. This trait was not devoid of considerable merit, as we shall see later, but its effect was to arouse the antagonism of both professors and fellow-students.

His observational powers were very highly developed, and he was only eighteen when, so it is stated (though the story may be apocryphal, like some others), he noticed that the oscillations of the swinging lamp in the cathedral of Pisa were isochronous—in other words, while the length of the swing gradually decreased, the time of swing remained practically unchanged. He conducted experiments on various bodies suspended on a string or in other

ways, and he found that this property was characteristic of any body so suspended and that the time of swing depended on the length of the string. He made an oscillating instrument by which small intervals of time could be measured, and this was used by physicians for measuring the rate of patients' pulses.

After leaving the University, Galileo gave private tuition in mathematics and mechanics, and in 1589, after applying unsuccessfully for professorships at a number of universities, he was appointed professor of mathematics at Pisa. The appointment was for three years and was renewable at the end of that period, but Galileo did not even complete his three years at Pisa. He excited a considerable amount of animosity by his independent judgment and his refusal to be trammelled by the teaching of Aristotle, which was then considered sacrosanct. It should be pointed out, however, that there has been much exaggeration regarding Galileo's experiments, in particular about the claim for priority.

Aristotle is usually credited with the statement that a heavy body must fall faster than a light one and in proportion to its greater weight, but this statement might mean that a body ten times as heavy as another will either fall ten times as fast or that it will fall ten times as far in the same time. It does not seem certain, however, that Aristotle taught either of these errors, and it may assist the reader if a quotation is taken from the *Physics* in the Oxford translation, 1930, edited by Ross:—

> To sum the matter up, the cause of this result is obvious—viz., that between any two movements there is a ratio (for they occupy time, and there is a ratio between any two times, so long as they both are finite), but there is no ratio of void to full.
>
> These are the consequences that result from a difference in the media; the following depend upon an excess of one moving [or 'moved'] body over another. We see that bodies which have a greater impulse [' trend,' ' momentum '] either of weight or of lightness, if they are alike in other respects, move faster over an equal space, and in the ratio

> which their magnitudes bear to each other. Therefore they will also move through the void with this ratio of speed. But that is impossible; for why should one move faster? (In moving through *plena* it must be so; for the greater divides them faster by its force. For a moving thing cleaves the medium either by its shape or by the impulse which the body that is carried along or is projected possesses.) Therefore all will possess equal velocity. But this is impossible.

This is the part of *Physics* that has aroused the traditional opposition to Aristotle's views on falling bodies. If we introduce the notion of up and down, which apparently is not found in the Greek, the teaching is certainly erroneous, but the special case selected by Aristotle's opponents is related to his argument on "the void." Galileo himself made a very serious error in his work *De Motu*, in which he gives his reasons why less heavy bodies, in the beginning of their motion, are carried more quickly than the heavier bodies. He even asserts that he tested the bodies from a high tower and found that at first the wood was carried more rapidly than the lead, but that later the lead preceded the wood by a long space.

Before Galileo published anything, a large number of writers objected to the view that bodies fall with a speed proportional to their weight. Among these we may notice such names as those of Simon Stevin (1605); Jacopo Mazoni (1597); Francesco Piccolomini (1597); Benedetto Varchi (1544); Giovanni Battista Benedetti (1553); Francesco Beato (*c.* 1544). In addition, there are many others whose names need not be mentioned. (The dates following the names refer to the times of the publication of the relevant works.) A few quotations will show that Galileo was by no means first to contradict the popular view of Aristotle's conception of the motion of falling bodies.

Varchi, in his *Questione sull' Alchemia*, says: "che quanto una cosa sia più grave, tanto più tosto discenda, il che la prova dimostra non esser vero"—"that the heavier a thing is, the quicker it descends, which the test proves not to be true."

John Philoponus, in his commentary on Aristotle's *Physics*

(533), anticipated the others just referred to, as the following quotation shows:—

> Here is something absolutely false, and something we can better test by observed fact than by any demonstration through logic. If you take two masses differing greatly in weight, and release them from the same elevation, you will see that the ratio of times in their movements does not follow the ratio of the weights, but the difference in time is extremely small; so that if the weights do not greatly differ, but one, say, is double the other, the difference in the times will be either none at all or imperceptible.

There is no record that Philoponus performed the experiment himself, but it is possible that the test suggested goes back to Alexandrian sources. Simplicius, a contemporary of Philoponus, refers to a work by Hipparchus in which he objected to the views of Aristotle regarding falling bodies. On the whole there is no sound reason for giving the credit to Galileo for first disproving a view which most people accepted from the passage in Aristotle's *Physics* previously quoted.

The story is told of Galileo dropping the weights from the leaning tower of Pisa as the professors and students were coming out after a lecture, thus giving them a spectacular demonstration of the falsity of Aristotle's teaching. This story, like some others in connection with Galileo, is now known to be apocryphal, but that does not detract from the importance of his experiments with falling bodies and bodies rolling down inclined planes, from which he showed that the interrogation of Nature was of infinitely greater value than the acceptance of the dicta of Aristotle.

The disproving of ancient tradition had a bad effect, from the mundane point of view, on Galileo, and he was obliged to resign his professorship before his three years of office had expired. To add to his troubles, the death of his father shortly before this event left Galileo with a surviving brother and four younger sisters depending on him, and he had a grim struggle with poverty. What a reward for one obsessed with the passion for truth!

Fortunately, soon afterwards, he secured an appointment as

professor of mathematics at Padua, and this inaugurated a very happy period for him. Padua was then in the territory of the Venetian Republic and was by far the most enlightened of the Italian States, its rulers encouraging freedom of thought. In days when it was dangerous to promulgate any truth which seemed to impugn the doctrine of the Church, such toleration was rare; but it had its reward, as the teaching of Galileo brought the University into great fame. Indeed, so great was its renown that students, not only from Italy, but also from other countries (and among these were a few princes of royal blood), flocked to Padua to learn from the eminent natural philosopher. The authorities obviously held him in very high esteem; in 1598, when his tenure of office for six years expired, they renewed his professorship for another six years, and again later on for life, with an increase of stipend each time.

His first contribution to astronomical discovery was made in 1604, when a new star appeared in the constellation of Serpentarius. He had, however, shown interest in astronomy many years previously. Before 1597 he was convinced that the Copernican view of the universe was the only correct one. In a letter to Kepler in August, 1597, in which he acknowledged the receipt of Kepler's first book, he stated that he had become a convert to the opinions of Copernicus many years earlier, and he admitted that the Copernican theory explained many phenomena otherwise inexplicable. His description of the new star as a vapour of extreme tenuity, driven off from the earth's atmosphere and reflecting the sun's rays, was scarcely worthy of so great an experimental scientist. In fairness to Galileo, however, it should be said that at that time he was not an astronomer, his attention having been largely taken up with terrestrial experiments; and his occasional incursions into the realm of astronomy were not at first productive of any great additions to the existing knowledge of the subject.

Galileo's fame as an astronomer rests on his observations, and these were due to the invention of the telescope. It is generally believed that the telescope was discovered by accident, an apprentice in the shop of Hans Lippershey, an optician in

Middelburg, having made the discovery while he was playing with some of his master's spectacles. Before this discovery in 1608, however, others claimed to have made use of the telescope. Roger Bacon (1214–94) had a good knowledge of optics and was supposed to have been acquainted with the telescope. Nevertheless, his own story about the telescope detracts from his claim. He stated that the invention of the instrument was known to Cæsar, who used it before the invasion of Britain to survey the country from the shores of Gaul. The claim that a countryman of our own—Leonard Digges—who died about 1571, understood the use of the telescope, is more authentic. Giambattista della Porta (1543–1615), a natural philosopher born of a noble and ancient family in Naples, professed to know a combination of lenses by which one could recognize friends at a distance of several miles. He stated that it was an invention of great utility and not difficult to make, but he added that "it must not be divulged, as not to be understood by the vulgar, and yet be clear to the sharp-sighted." He gave an obscure description of the instrument, but it is uncertain from this if he had really anticipated the Dutch boy.

The news of the discovery at Middelburg reached Italy in the following year, and Galileo, though without any clear directions regarding the construction of the instrument, was able to make one himself after a few experiments with a convex and concave lens. His first instrument magnified three times, but he continued to make larger and better ones until he reached his fifth, which magnified thirty times. With this he carried out observations of the moon. He had been at variance with the Aristotelian philosophers previously, but this telescope was destined to bring him still more into conflict with them, because it showed that the surface of the moon was full of inequalities, not perfectly smooth and spherical, as the Aristotelians believed.

Galileo was not the first to use the telescope for celestial purposes; this honour must be given to Thomas Harriot, an English mathematician, and to Simon Marius, a German. The credit has been assigned to Galileo largely because he was so assiduous in his observations. His independence of mind in interpreting

his results, and also the fact that he realized, as no others did, the immense value of the instrument for astronomical progress, contributed largely to enhance his fame.

In 1910 Galileo published an account of some of his observations in *Sidereus Nuncius*. This dealt with his discoveries on the moon's surface, and his observation of Jupiter's satellites, and also of a large number of stars invisible to the naked eye. He discovered the satellites on January 7, 1610, and named them "Medicean planets," in honour of his patron, Cosmo de Medici, the Grand Duke of Tuscany. The name "satellite," suggested by Kepler as applicable to the new bodies as well as to the moon, was later adopted, as the term "planet" could not very well be used for bodies which revolved round the sun and also round a planet.

Galileo's discovery of the four satellites of Jupiter (seven more have been discovered since his days) tended to discredit the views of Ptolemy and Aristotle, who knew nothing about such bodies. The outlook of even men of science in those days can be judged by the following quotation from Sizzi, a so-called astronomer of Florence, who, with many others, was bitterly opposed to Galileo because he had upset the reasoning of the schoolmen :—

> There are seven windows given to animals in the domicile of the head, through which the air is admitted to the tabernacle of the body, to enlighten, to warm, and to nourish it. What are these parts of the microcosmos? Two nostrils, two eyes, two ears, and a mouth. So in the heavens, as in a microcosmos, there are two favourable stars, two unpropitious, two luminaries, and Mercury undecided and indifferent. From this and many other similarities in Nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of the planets must necessarily be seven. Moreover, these satellites of Jupiter are invisible to the naked eye and therefore can exercise no influence on the Earth, and therefore would be useless, and therefore do not exist. Besides, the Jews and other ancient nations, as well as modern Europeans, have adopted the division of

> the week into seven days, and have named them after the seven planets. Now, if we increase the number of the planets, this whole and beautiful system falls to the ground.

It would be difficult to imagine anything more fatuous than the views expressed by Sizzi, yet they were typical of the outlook at the time. Sizzi even refused to look through the telescope, probably fearing the consequences if he saw the satellites and was obliged to contradict the evidence of his senses. Even more enlightened astronomers objected to this particular discovery; among them may be noted Martin Horky, a German who had studied under Kepler and who published a pamphlet proving that the satellites of Jupiter did not exist. After proving their non-existence he proceeded to discuss their nature, what they were like, and why they existed!

Although Galileo's discoveries earned him much abuse, they also brought him a considerable reputation, and in the summer of 1610 he accepted the offer of a professorship at Pisa and also the position of "First Philosopher and Mathematician" to the Grand Duke of Tuscany. These offices, to which no definite duties were attached, enabled him to live comfortably and to devote his time to astronomical pursuits. Although the appointment was most gratifying to Galileo, it was not unattended with dangers, as some of his friends pointed out to him. While he was in the Venetian Republic he was safe from the Papal power, as the rulers were jealous of Rome, and, in addition, had no love for the Jesuit party. He was warned, however, that in Tuscany he would not enjoy the same protection as in Venice, and, although for some years he was left undisturbed, he discovered later that the warning was not based on pure imagination.

It is unnecessary to dwell on his various discoveries—Saturn's ring (the nature of which he could not explain), solar spots, the phases of Venus, etc.—as our object is to show how he came into conflict with the Papal power, and so figured in one of the most melancholy episodes of the history of scientific thought and development.

Extreme Aristotelians and the more ignorant among the clergy

were persistent in their denunciation of Galileo. Probably conscious of the growing hostility to his views, he paid a visit to Rome in 1611. He met with a most cordial reception there, and was treated with great friendliness by several cardinals and others; even Pope Paul V evinced no opposition to his views. A number of the Church dignitaries looked through his telescope, and it does not appear that Cardinal Barberini, to whom he was introduced and who showed considerable interest in his discoveries, displayed the slightest hostility towards him. But when Cardinal Barberini later became Pope Urban VIII the conflict grew very acute and led to the most unfortunate consequences.

Soon after Galileo returned from Rome he was drawn into controversies regarding the relative validity, in scientific matters, of observation and reasoning, and of the authority of the Church and the Bible. In 1611, the year in which Galileo visited Rome, a tract was published which maintained that teaching the existence of Jupiter's satellites was unscriptural, and in the following year Galileo consulted Cardinal Conti regarding the astronomical teaching of the Bible. Cardinal Conti expressed the opinion that the Bible seemed to discourage both the Aristotelian doctrine of the immutability of the heavens and the Copernican doctrine of the motion of the earth. Notwithstanding this opinion, Cardinal Barberini thanked Galileo for the presentation copy of his work on sun-spots, in spite of the fact that this book quite definitely proclaimed his adherence to the Copernican doctrine.

Matters drifted towards a crisis in the next two years. In 1613 Father Castelli, an adherent of Galileo's views, was appointed professor of mathematics at Pisa, but he had special directions not to lecture on the motion of the earth. Soon after his appointment he was drawn into an argument on the relation of the Bible to astronomy, and went so far as to quote Galileo in support of his views. As a result Galileo wrote a long letter to Castelli, expressing his opinions, and this letter was circulated in manuscript to the Court. In consequence Galileo was secretly denounced to the Inquisition in 1615. Early in 1616 a body of theologians known as the Qualifiers of the Holy Office made a report on the Copernican doctrines as follows:—

> That the doctrine that the sun was the centre of the world and immoveable was false and absurd, formally heretical and contrary to Scripture, whereas the doctrine that the earth was not the centre of the world but moved, and has a further daily motion, was philosophically false and absurd and theologically at least erroneous.

Soon after this report was promulgated it was decided to censure Galileo, and Cardinal Bellarmine was directed to summon him and to admonish him to abandon certain opinions. Very soon after he had been admonished his opinions were condemned, and three books containing Copernican views were placed on the *Index*. One of these was completely prohibited, but *De Revolutionibus* and another were merely suspended until certain corrections were made. The corrections that were inserted in *De Revolutionibus* were published in 1620, and were of a minor character, making it appear that the views of Copernicus were only hypotheses convenient for calculations. So far as Galileo was concerned, the issue of the inquiry in 1616 was not unsatisfactory, and he even obtained from Cardinal Bellarmine a certificate stating that he had not abjured his views nor had he done penance for them.

Although certain difficulties arose after this, they were of a minor character, and apparently Galileo did not take a very firm stand on the Copernican doctrine, as the following quotation from *Il Saggiatore* (*The Assayer*), published in 1623, will show :—

> Since the motion attributed to the earth, which I, as a pious and Catholic person, consider most false, and not to exist, accommodates itself so well to explain so many and such different phenomena, I shall not feel sure . . . that, false as it is, it may not just as deludingly correspond with the phenomena of comets.

*Il Saggiatore* was dedicated to Pope Urban VIII, formerly Cardinal Barberini, and, although it contained thinly veiled Copernicanism, the Pope was very pleased with the work. When Galileo visited the Pope, soon after the publication of the book, he was received cordially, and the Pope even promised him a pension for his son. On one point, however, the Pope was

adamant: he refused to withdraw the decree of 1616, in spite of Galileo's earnest appeal for its withdrawal. Matters later reached a crisis through Galileo's great astronomical treatise, *Dialogue on the Two Chief Systems of the World, the Ptolemaic and Copernican*, which appeared, after certain delays in obtaining the licence for its publication, in 1632.

This book is in the form of a dialogue between Salviati, a Copernican, and Simplicio, an Aristotelian philosopher, with a third person, Sagredo, ostensibly neutral but generally intervening on the side of Salviati or being easily convinced by his arguments. Salviati shows that the Aristotelian doctrine of the immutability of the heavenly bodies is not confirmed by observations of the sun, moon, and comets, while the earth's motion is demonstrated by Jupiter's satellites, the phases of Venus, and the variations in the apparent sizes of Mars. The great simplicity of the Copernican system is shown by the fact that all motions of revolution and rotation are represented as taking place in the same direction, from west to east. In addition, the Ptolemaic system indicates considerable differences in the velocities of the various stars, those near the pole moving slowly, while those near the equator move rapidly.

It is unnecessary to deal with the contents of the work in full; it was a powerful and practically unanswerable plea for Copernicanism. At first it met with great success, but later strong opposition was aroused and some of Galileo's enemies persuaded the Pope that "Simplicio," in the dialogue, was intended to represent himself—an implication which was a grievous injury to his vanity. About the middle of 1632 a special commission was appointed to inquire into the matter, and very soon an order was issued forbidding the further sale of the book. The commission reported that Galileo had deviated from the hypothetical standpoint by maintaining decidedly that the earth moves and that the sun is stationary, and in September a Papal mandate was issued requiring Galileo to appear before the Inquisition. Galileo attempted to avoid complying with the summons, and through the medium of the Tuscan Court he pleaded age and infirmity, which delayed his appearance at Rome. The Pope finally ordered that he should be brought by force, if necessary, and also in

chains, and Galileo, dreading such an ordeal, set off for Rome early in 1633. A brief outline of the sequel follows.

Although offenders under trial by the Inquisition were generally confined to prison, Galileo was allowed a considerable amount of liberty, and lived with Niccolini, the Tuscan ambassador, during most of the trial. During the three weeks spent inside the buildings of the Inquisition he was quartered in comfortable rooms, and was allowed to correspond with his friends and to enjoy various other privileges. There was no question of close or solitary confinement at any time, and it would be incorrect to describe his stay at Rome, prior to the trial, as spent in "prison." At the first hearing of his case he defended himself against the charges of having violated the decree of 1616 by saying that his book had treated Copernicanism as a mere hypothesis, which was not a violation of the decree, and that in no other way had he accepted the doctrine. Before the next hearing the commission examined his book and reported that it did decidedly uphold the obnoxious doctrines; this information was conveyed to Galileo before the trial. The Commissary-General of the Inquisition in the meantime saw him privately and advised him to adopt a more submissive attitude—a hint which he readily accepted. When the hearing took place Galileo pleaded that he had read the book again and had recognized portions of it as sustaining the Copernican view more strongly than he had previously suspected. He went so far as to offer to write a continuation to the Dialogue which would refute the arguments in favour of Copernicanism. The final examination took place on June 21 under threat of torture (though no physical torture was actually applied), and the following day sentence was passed on him. The words of his conviction are as follows:—

He was convicted "of believing and holding the doctrines—false and contrary to the Holy and Divine Scriptures—that the sun is the centre of the world, and that it does not move from east to west, and that the earth does move and is not the centre of the world; also that an opinion can be held and supported as probable after it has been declared and decreed contrary to the Holy Scriptures."

In the large hall of the Dominican Convent of Santa Maria

Sofia Minerva at Rome, in the presence of seven cardinals, Galileo was compelled to say:—

> I abjure, curse, and detest the said errors and heresies and generally every error and sect contrary to the said Holy Church; and I swear that I will nevermore in future say or assert anything verbally or in writing which may give rise to a similar suspicion of me; but that if I shall know any heretic or anyone suspected of heresy, I will denounce him to this Holy Office or to the Inquisitor and Ordinary of the place in which I may be.

In addition to his abjuration he was condemned to the formal prison of the Holy Office during the pleasure of his judges—a sentence commuted by the Pope into one of confinement at a country house near Rome, belonging to the Grand Duke. He was also condemned to repeat the seven penitential Psalms once a week for three years. Later he petitioned to be allowed to return to Florence, and he was permitted to retire to his country house at Arcetri; but it was laid down as a condition that he should not leave it without permission.

Although Galileo was now an old man and his intercourse with his scientific friends was carefully watched, his career was not yet ended. Failing sight prevented him from making many observations, but he was able to devote himself to dynamical problems, and three years after his sentence he completed his work *Dialogues on the Two New Sciences*, which could not be printed in Italy owing to papal prohibitions, but was published in Leyden in 1638. Nearly half a century later, Newton enunciated his three laws of motion, and these were, generally speaking, based on the work of Galileo. He built up a theory of falling bodies in which occurs for the first time the idea of uniform accelerated motion, but this was not mere theory; it was the outcome of some of his experiments conducted many years previously. He was able to work out a number of deductions relating to space described, velocity, time of fall, etc., not only in the case of bodies falling freely, but also for bodies rolling down inclined planes.

In addition to his work on dynamical problems Galileo was able to carry out a few observations, in spite of failing eyesight; and his discovery of the librations of the moon, during his later years, was a great achievement for one suffering from the handicap of partial blindness. A full inquiry into the subject of the moon's librations ceased at the end of 1636, when he became totally blind. He died on January 8, 1642, in his seventy-eighth year. A project for a public funeral, a funeral oration, and a monument was set on foot immediately, but was vetoed by the ecclesiastical authorities. Half a century after his death, however, a memorial was erected to him by his disciple Viviani. His books remained on the *Index of Prohibited Books* until the publication of the 1821 edition, but in the 1835 edition they were omitted, and they have not since been listed.

The treatment of Galileo is an episode which many would like to forget. It reflected no credit on the Church, which tried to suppress the truth. On the other hand, recriminations avail nothing, and we should feel profoundly thankful that it is now possible to promulgate truth without the haunting fear of persecution by ecclesiastical power.

It has been pleaded, on Galileo's behalf, that he was justified in committing perjury (his abjuration practically amounted to this) on the ground that, while revealed truth may require martyrs, scientific truth requires none. It is outside the province of this book to deal with the question, though in extenuation of Galileo's action it may be pointed out that the Inquisition would almost certainly have resorted to torture if he had not given in. During Galileo's life Giordano Bruno had been burnt alive at Rome for writings which supported the Copernican astronomy and also contained religious and political heresies; the thought of a similar ordeal could not have been very pleasant for an old man of seventy. Even if his submission was due to considerations of personal safety only, we should not be too ready to condemn him.

There is another point that is often overlooked: Galileo was a very sincere (even if he was not a very orthodox) member of the Church. At the present time there are devout members of the Church who are convinced, from their own observations, as

Galileo was, that certain tenets are wrong, and yet feel that in some way the Church is correct in its interpretation. While it is not easy to understand the mentality of such people, this does not alter the fact that they exist and are often very conscientious in their ordinary dealings with their fellow-men. It is quite possible that Galileo was able to keep his mind in water-tight compartments, as many others are able to do; and here it may be pointed out that the words attributed to him when he recanted, "*Eppur si muove*"—"and yet it does move"—were not spoken by him. The literature relating to Galileo denies this story, and it has been traced to a work published in London more than a hundred years after his death. It is important to notice this point, because it tends to support the view just referred to—that Galileo may have thought the Church was quite correct in a certain sense, even if he could not explain why or how. If he had used the words alleged to have been used by him, this view would be untenable.

Although Galileo is generally thought of as an astronomer, most of his original work was in dynamics, where he practically created a new science. Previous generations had laid some kind of a foundation in astronomy, and without Copernicus Galileo's astronomical pronouncements might have been much more circumscribed; but in dynamics he had inherited nothing but the very worst traditions. These had to be completely discarded before he could find a secure basis on which to construct an edifice—small, it is true, but destined to become a super-edifice in later generations.

We shall conclude this chapter by quoting a passage from Castelli, a friend of Galileo and an adherent to his views. Physical darkness had closed around Galileo, as he was totally blind, but his mental powers were unimpaired:—

> The noblest eye which nature ever made is darkened—an eye so privileged and so gifted with rare qualities that it may with truth be said to have seen more than the eyes of all who are gone and to have opened the eyes of all who are to come.

CHAPTER XIII

# ISAAC NEWTON

ISAAC NEWTON was born at Woolsthorpe on December 25, 1643 (according to the unreformed calendar which was then in use in England). He was very delicate as a child and was scarcely expected to survive, yet he lived for more than eighty-four years. In his boyhood the delicacy which threatened his future seems to have disappeared, in part at least, and after attending small schools at Stoke and Skillington he went, at the age of twelve, to King's College, Grantham. When he was fourteen his mother, after the death of her second husband, withdrew him from the school so that he might look after the farm. Fortunately for the advancement of science, Newton showed no aptitude for farming, and after trying for two years to learn something about the subject he was sent back to Grantham, and from there, in 1661, he went to Trinity College, Cambridge. His career at Trinity College was not specially distinguished, and in 1665 he graduated in the ordinary course as Bachelor of Arts, and two years later was elected a Fellow. Before he took up his duties the outbreak of the plague at Cambridge necessitated the closing of the University, and he returned to Woolsthorpe.

In the peace of the Lincolnshire village Newton turned his attention to the problem of the planetary system. Kepler had attempted to explain the motions of the planets by a special influence emanating from the sun, and he looked for some kind of force to maintain their motions by pushing them along. Galileo had formulated his law about moving bodies—that they would continue to move indefinitely unless some force intervened to stop them—but he had not developed the idea. During Newton's time Giovanni Alfonso Borelli (1608–79) had pointed out that a body revolving in a circle or similar curve had a tendency to recede from the centre. In the case of a planet possessing the same tendency, owing to its revolution round the sun, it seemed possible that some kind of attraction towards the sun might counteract the centrifugal force.

Here we see the idea—to be developed later—that the motion of a planet does not necessarily require a force pushing it on in the direction of its motion, but that a force directed at right angles, or at least nearly at right angles, to the direction of its motion, suffices. Huyghens developed this idea without special reference to the planets, and he obtained some important quantitative results. Although he published these before Newton had worked out similar results, it is certain that Newton's discoveries were quite independent of those made by Huyghens.

The story of the apple falling from a tree while Newton was sitting in the garden at Woolsthorpe and directing his thoughts to the universal law of gravitation, has often been told, but it is difficult to say whether this story is true. He would probably have thought about such a law in any case, though the fall of the apple may have suggested that the force which made it fall was the same force which made the moon revolve around the earth, and the planets around the sun. On calculating the distance through which the moon fell towards the earth each second, and calculating how far she should fall on the assumption of the inverse square law, Newton found that there was a discrepancy, and it is said that the discrepancy was so great that he then abandoned the idea of the inverse square law and turned his attention to other branches of science. It is generally believed that the discrepancy arose because Newton had not used the correct radius of the earth in his investigations, but in comparatively recent times reasons have been shown for doubting this explanation. However, it is certain that he dropped the subject on his return to Cambridge in 1667, when the perils of the plague had passed.

Newton was elected to a minor Fellowship in the October after his return to Cambridge, and to a major Fellowship the following year. In October 1669 he was appointed to the Lucasian Chair of Mathematics, and as his duties were comparatively light he was able to devote himself to research in various branches of science. It would occupy too much space, and would not serve any useful purpose in the present book, to dwell on all Newton's work in optics and other fields, and we must be content

to limit our survey to his astronomical work—more especially in dynamical astronomy. It should be pointed out at this stage that Charles II showed a great interest in Newton's work and granted him a special dispensation—on Newton's petition—from ordination. It was the rule at Cambridge that on the expiration of a College Fellowship re-election could take place only if the Fellow were ordained. Although Newton was a very religious man, he did not want to be circumscribed by creeds, and this led to his petition to the King. Later we shall examine Newton's influence on religious movements in this country.

The fame of Newton rests chiefly on his book, *Philosophiæ Naturalis Principia Mathematica*, the manuscript of which was submitted to the Royal Society in 1686. Edmund Halley—an astronomer fourteen years Newton's junior—was asked to report to the Council of the Royal Society as to the possibility of having the book published, and it was decided on May 19 that the work should be printed forthwith. Unfortunately the Society, at the time, was not in a very strong financial position, and in the following month it was decided to leave the publication to Halley, who agreed, and even defrayed the cost. In July 1687 this momentous work appeared, and Newton immediately took his place as a leading man of science.

Newton's law of universal gravitation had far-reaching results. This law states that every particle of matter in the universe attracts every other particle with a force varying inversely as the square of their distances apart and directly as the product of their masses. This law explained the laws of falling bodies, which Galileo had expounded, and also the laws of planetary motion formulated by Kepler. It effected a beautiful synthesis between astronomical and dynamical observations, so that a number of apparently disconnected facts were easily explained and shown to be the outcome of one general law. By the discovery of this law Newton laid the foundations of physical astronomy, a science which was destined to develop to an extraordinary degree in later centuries. While some of his theories were left in an imperfect state because other sciences had been only partially developed, subsequent discoveries tended to confirm his law. It may be

pointed out here that the Einstein hypothesis in comparatively recent times has introduced very small modifications in Newton's laws; this matter will be dealt with later.

The *Principia* ends with a general scholium in which Newton maintains that "the whole diversity of natural things can have arisen from nothing but the ideas and the will of one necessarily existing being, who is always and everywhere, God Supreme, infinite, omnipotent, omniscient, absolutely perfect." When Bentley inquired how the movements and structure of the solar system could be explained, Newton replied: "To your query I answer that the motions which the planets now have could not spring from any natural cause alone, but were impressed by an intelligent Agent. . . . To make this system with all its motions required a cause which understood and compared together the quantities of matter in the several bodies of the sun and planets and the gravitating powers resulting from thence . . . and to compare and adjust all these things together in so great a variety of bodies, argues that cause to be not blind and fortuitous, but very well skilled in mechanism and geometry."

Newton believed in the direct intervention of an intelligent Agent, but modern astronomy substituted the nebular hypothesis of Kant and Laplace, or, in more recent times, the tidal theory of the disruption of the sun, the planets being formed from the ejected matter. It is true that these theories and various others formulated to explain our planetary system have been rejected, or considerably modified, but this does not prevent the cosmogonist from endeavouring to explain the origin of the solar system without postulating direct divine intervention.

Newton's arguments are now considered similar to those used by Paley and others who showed the wonderful contrivances to preserve the species, but such arguments have long ceased to interest anyone. They are unsafe, and cut both ways, because the array of facts suggesting design has an equally dysteleological application.

Nature presents so many instances of dysteleology that it would be impossible to deal with them, and it will be sufficient to consider the case of the Entozoa—a term applied to such worms as

are parasitic within the bodies of other animals, and which obtain their nutriment by the absorption of the juices of these. A remarkable feature in their structure is the low development of their nutritive system and an extraordinary development of their reproduction apparatus. The common *tænia*, or tape-worm, has neither mouth nor stomach, and the so-called "head" is merely an organ for attachment. The segments of the *tænia* contain a generative apparatus, the male and female sexual organs being so united in each segment that the *tænia* can fertilize and bring to maturity its own very numerous eggs. These wonderful contrivances may arouse our admiration of Nature's solicitude for the preservation of the species, but they may also arouse a feeling of loathing when it is obvious that her solicitude for the preservation of one species is attended by the destruction of another species which is usually regarded as higher in the evolutionary scale than is *tænia*. The argument from design proves nothing.

Before proceeding to consider the work of a few pioneers who succeeded Newton we shall look at the effect of astronomical development on certain branches of thought—theology in particular.

The rise of the Deists in the seventeenth century was largely due to previous discoveries in astronomy. Although this theological thought was not confined to England, it had England as its principal source, and, widely as the Deists differed in certain matters of belief, they agreed on one main principle: they sought to establish not only the certainty but also the sufficiency of natural religion in contrast to revealed religion; hence they ignored the Scriptures or impugned their infallibility. It would be very tedious to outline the positions adopted by all the English Deists, and it will suffice to give a short résumé of the arguments set forth by a few of them.

William Wollaston (1669–1733) was the author of *The Religion of Nature*, and the system of morality which he advocated was entirely independent of revelation. Some theologians were shocked because he made no direct reference to the Bible, but he found this unnecessary, deducing the ten commandments from general principles without any direct appeal to Moses. Although

he admitted the doctrines of a particular Providence and of the efficacy of prayer, he attempted to reconcile them with a philosophical view of the uniformity of Nature. His ultimate appeal was to reason, and by reason he attempted to prove the immortality of the soul, though it is very doubtful if many to-day would accept his method of proof.

Wollaston starts with the assumption that the Almighty is bound to form no creature in whose existence the unavoidable pains will, on the whole, overbalance the pleasures. If each being has not a surplus of happiness he has himself to blame for the suffering, but the prevailing misery of the human family is too obvious, and some solution for this problem must be sought. One, and only one, solution can be found: the existence of a place where proper amends may be made, and if such does not exist, or in other words if the soul is not immortal, then there is no God on whom we may depend, or else He is an unreasonable Being. He paints the world in a sombre fashion to bring out more brightly the prospects of the future life.

Only once does Wollaston refer to revelation, and that is when he becomes aware of his need for a guide. His argument for the reward of virtue in the next world is very weak. He argues that inequalities in this world are a cogent reason for an equality hereafter—a deduction that very few to-day would be prepared to accept.

Matthew Tindal (1657–1733) wrote *Christianity as Old as Creation*, the main thesis of which is that God is infinitely wise, good, just, and immutable, and that human nature is also unchangeable. Hence the law which God lays down for man will be perfect and unalterable. One great difficulty to Tindal was that of an historical revelation. How can we render homage to God as creator and ruler if at the same time we identify Him with one who selected an obscure tribe as the recipient of His favours? This question would naturally arise in Tindal's mind because he could not conceive of a Deity who was capricious, and for this reason he repudiated all arbitrary enactments which, he believed, had been foisted by priestcraft into the original code. Although he did not deny the reality of revelation, he held that

it was superfluous and merely duplicated the original document. He drew a distinction between natural and revealed religions which did not differ in their substance, but merely in their mode of communication, natural religion being the internal, and revealed religion the external, revelation of the will of God. Assuming that God must have dealt equally with all men, it follows that any doctrines not revealed to all could not be doctrines imposed by the will of the Creator.

Many other well-known Deists might be mentioned, such as Lord Herbert, Toland, Shaftesbury, and Collins, but we shall deal with the writings of only one—Charles Blount (1654–93). He was not a man of great ability, and his *Just Vindication of Learning and of the Liberty of the Press*, published in the year of his death, was a flagrant plagiarism from Milton's *Areopagitica*, but it had a good effect in exposing the folly of the censorship. Before this he had expanded Hobbes's arguments against the Mosaic authorship of the Pentateuch, and had also pointed out the inconsistency between the account of creation given in Genesis and the Copernican theory. (The argument was mainly that adopted by Burnet in *Archæologia Philosophica.*) He drew attention to the double narrative in the story and assumed that the account was intended to be taken ethically, not physically, with the object of eliminating polytheistic notions. Naturalistic explanations of some of Christ's miracles were suggested, and he dwelt on the tendency of men to discover miracles attending the birth and death of heroes—thus foreshadowing a mythical theory. He upheld the view that many errors in religion have been invented or deliberately maintained for the preservation of good government or in the interests of the class which invents or maintains them.

There were many reasons why men in the seventeenth century were disposed to discard the fetters of tradition and of scholastic systems and to follow the light of Nature. When the significance of the Copernican system was fully realized the centre of the universe shifted from our planet, which shrank into a mere speck in the great cosmos. Beliefs regarding the supposed direct interference of Providence in the affairs of men received a rude

shock, and Christian apologists like Newton, Clarke, Butler, Chalmers, and others, refer to events in the material world as brought about, not by isolated interpositions of divine power exerted in each particular case, but through the establishment of general laws. Newton's laws, which had a universal application, would naturally encourage this view and would lead men to take a wider and also a nobler conception of the universe.

The theological view, the narrowness of which it is almost impossible for us to realize to-day, was replaced by a secular view which, though meeting with violent opposition from many quarters, was destined to supersede the older conception. The intellectual cravings of the time found little satisfaction either in the Catholic or the Protestant tradition. In the realm of physics René Descartes (1596–1650) had prepared the way for the triumph of a mechanical explanation of the world, based on Newton's system. It is not surprising that the Deist movement should arise in such an atmosphere, but it is rather surprising that it collapsed almost as quickly as it arose.

What was the explanation for the rapid decay of Deism? It certainly cannot be attributed to a clear victory through the arguments of the Christian apologists, because the Christians met the Deists more than half-way. The real cause of its decay was its own internal weakness. Human nature is generally more influenced by the emotional than by the logical appeal, and there was very little in Deism that was associated with people's most powerful emotions. If a deity is to excite any real zeal in its worshippers, it should be something more than a mere metaphysical conception. Perhaps this in part explains why Unitarianism has made so little progress and has failed to lay much hold on people in any country, whereas numbers of sects with extraordinary tenets flourish and increase. Among the latter sects emotionalism plays a very important part.

After the decay of Deism internal evidence for Christianity became of little consequence, and the inquiry was directed to the external evidence, which became more and more important. Arguments became almost entirely of an historical nature.

## CHAPTER XIV

# FROM NEWTON TO RECENT TIMES

NEWTON died in 1727, and the progress of astronomy after his days was relatively rapid. It will be necessary to glance at the work of only a number of pioneers in different branches of the subject from the days of Newton till modern times. Those who desire a comprehensive survey must consult special works which deal with this side of astronomy.

John Flamsteed was born on August 19, 1646, and owing to ill-health his early education was sadly neglected. He was sixteen years old before he learned arithmetic, but in spite of this initial handicap he showed an interest in, and an aptitude for, astronomy. With a hand-made quadrant he was able to make simple astronomical observations. Before he was twenty he had constructed a catalogue of 70 stars and had made a number of important observations. He went to Cambridge later, took his degree when he was twenty-eight, and was then ordained. He hoped to settle in a parish in his native county of Derbyshire, the gift of which belonged to his father, but circumstances arose which frustrated this scheme.

In 1674, the year in which Flamsteed took his degree, Le Sieur de St. Pierre, a Frenchman, came to London with the object of arousing interest, among English men of science, in a scheme for determining longitudes with more accuracy than they had been previously measured. A committee to which Flamsteed was appointed was formed to consider the matter, and Flamsteed indicated the hopelessness of applying the method because of the inaccuracies of observational astronomy. The report of the committee was forwarded to the Government, and King Charles II, who saw it, was very surprised that the positions of the stars in the catalogue were so untrustworthy. He decided that they should be re-observed, examined, and corrected for the use of his seamen, and this decision was followed by the establishment of the Royal Observatory, Greenwich, in 1675. Flamsteed was

placed in charge, and was paid £100 a year for his work, which was carried on without an assistant. It is a terrible story of a struggle for more than forty years against ill-health; but before he died, in 1719, he had determined the positions of nearly 3,000 stars with greater accuracy than had ever been done previously.

It was unfortunate that the relations between Flamsteed and Newton should have been so unfriendly. Flamsteed was making certain observations on the moon which Newton required for his work, and Flamsteed withheld the results as long as possible from Newton. Quarrels arose over other matters, and the trouble was not mitigated by the fact that Halley, a very close friend of Newton, was intensely disliked by Flamsteed. Such feuds were unworthy of renowned men of science, and retarded the progress of that particular branch in which both were specially interested.

Edmund Halley was born at Shoreditch on October 29, 1656, and at an early age showed a remarkable aptitude for mathematics. He entered Queen's College, Oxford, when he was seventeen, and when he left there, in 1676, he went to St. Helena and set up a temporary observatory (his father providing the funds), where he catalogued 341 southern stars. His subsequent work included the computation of the orbits of comets, which Newton showed obeyed the law of gravitation, like the planets. On looking over old records, Halley was impressed by the fact that bright comets similar to that of 1682 had appeared at intervals of about 76 years, and he foretold the return of the 1682 comet in 1758, a prediction which was fulfilled, and the comet was named after Halley.

Reference may also be made to Halley's discovery of the proper motions of some stars, Aldebaran, Sirius, Arcturus, and Betelgeux. He noticed that in the case of Sirius there was a discrepancy between his observations and those of Tycho Brahe, and that the other three had changed their positions since the days of Ptolemy. This discovery marks a forward step in astronomy, being the first proof that the "fixed" stars were not fixed, but were in motion. In 1715 Halley noticed the corona during a total eclipse of the sun, and also the chromosphere, which he described as "a very narrow streak of dusky but strong red light."

After the death of Flamsteed in 1719, Halley was appointed Astronomer Royal, but, as Flamsteed's widow had removed all the instruments, he was unable to make any observations until the Board of Ordnance granted £500 for further equipment. He carried out a series of observations to determine more accurately the irregularities in the motion of the moon, but he died in 1738, before his scheme of observations had been completed.

We pass over a number of astronomers of note until we come to the work of Pierre Simon Laplace, born in 1749. Two great books stand to his credit, the first of which, *Mécanique Céleste*, appeared between 1799 and 1825 in five volumes. In this he deals with the solar system as a great machine moving under the influence of immutable laws. He could not foresee a breakdown of such a system, which seemed to have been arranged at its origin for eternal duration. When he went to make a formal presentation of his work to Napoleon Bonaparte, the Emperor remarked: "M. Laplace, they tell me you have written this large book on the system of the Universe and have never even mentioned its Creator." Laplace replied: "Sire, I had no need for any such hypothesis."

Laplace's reply has been construed in two senses. It has been alleged that he meant it was superfluous to adopt the hypothesis of a Creator, because such would naturally be assumed; but it is more probable that he meant that his system could do without such an hypothesis and that it was quite irrelevant whether he postulated a Creator or not. In a subsequent work, *Exposition du System du Monde*, he deals especially with the origin of the solar system, a brief explanation of which follows.

Laplace began with a sun with an atmosphere extending out beyond the orbit of the most remote planet, and in equilibrium under the gravitation of the central mass and its own gaseous expansive force. He assumed that this nebulous mass had a very high temperature and that it had a slow rotation. As it contracted, its angular speed of rotation would increase, and at different stages it would discard some of its material in the form of rings, each of which would condense, in the course of time, into a planet. Before the planets could condense into the solid

condition, some of them, rotating as our earth and other planets rotate, would eject matter from their equatorial regions just as the contracting nebula ejected matter which formed the planets, and from this matter were formed the satellites.

Many phenomena connected with the solar system could be explained on the basis of Laplace's theory, but a long time ago the theory was shown to be untenable. Even while Laplace was alive the discovery by Herschel of retrograde motion of the satellites of Uranus was a serious blow to the prestige of his hypothesis. Since then, so many objections have been urged against the beautiful scheme of Laplace that it has been abandoned and more modern hypotheses have been formulated, none of which is free from difficulties. At present there is no consensus of opinion regarding the precise manner in which our planetary system has evolved.

Friedrich William Herschel, born at Hanover in 1738, might easily be described as the greatest of all astronomers. We are not concerned with the series of events which caused him to settle down in England, or with his work as a teacher of music for many years before he took up astronomy. It is said that his interest in the subject was aroused by reading *Astronomy Explained upon Sir Isaac Newton's Principles*, written by James Ferguson, the Scottish shepherd-boy astronomer, and published in 1756. Herschel's astronomical investigations were very wide, but his work on the stars was his main preoccupation. Two important discoveries in stellar work may be mentioned. The first was that the sun (a star on the same footing as other stars) was not stationary, but was in motion, the planets and satellites sharing this motion with it. This was not, of course, an accidental discovery. After Halley had shown the existence of proper motion of four bright stars, many believed that the sun might also move, and Herschel undertook the task of discovering if this was true. Selecting seven bright stars for observation, he concluded that the sun was moving towards the constellation of Hercules. Subsequent research of a more refined nature has corroborated his results.

Another important discovery related to double stars, which,

though known before Herschel's days, had not been systematically studied. He suspected that many of the double stars were not merely visual doubles—that is, lying nearly in the same line of sight—but that they were physically connected. Later he showed that a number of them were revolving around one another—confirmatory evidence that the law of gravitation held not only in the solar system, but in the sidereal systems as well.

Herschel was the first to attempt, systematically, to determine the precise form of the Milky Way, and his method was to make counts of the number of stars visible in the field of his 19-inch reflecting telescope when he turned it to various parts of the heavens. He came to the conclusion that the system of stars is like a grindstone, with a diameter of about 6,000 light-years. The estimate of the size of the Galaxy was very much too low, but this is easily understood when we remember that the telescope he used was small in comparison with the powerful equipment of the modern astronomer.

Herschel's son, John Herschel, carried on this work not only in the northern, but also in the southern hemisphere. He erected his 20-foot reflector at Feldhausen, near Cape Town, and his discoveries included over 1,200 double stars and over 1,700 nebulæ. In his programme of star-gauging he counted 70,000 stars and gauged 2,300 star-fields. At the age of forty-six he returned from the Cape and, strange to say, his work on observational astronomy ceased, though he published a good deal on astronomy later. Since the days of the Herschels the structure of the sidereal system has presented one of the major problems of astronomy, and much still remains to be done in this sphere.

In 1838 Bessel announced that he had been successful in measuring the parallax of a star—61 Cygni—and about the same time Struve and Henderson determined the parallaxes of Vega and $\alpha$ Centauri, respectively. This work marked an important epoch and revealed for the first time the distances of the stars. Struve's value for Vega was not very accurate, but those of Bessel and Henderson were remarkably good, as later results have shown. The distance of 61 Cygni was found to be about 40 million million miles, and that of $\alpha$ Centauri about half this number.

More refined methods are now used for determining the distances of the stars—not only those comparatively close to us, like 61 Cygni and $\alpha$ Centauri, but also those separated from us by hundreds of thousands of light-years. The development of this branch of astronomy has produced a profound change in our conception of the universe, the extent of which is beyond the power of the mind to grasp adequately. Indeed, Wilhelm Struve's researches led him to believe that the stellar system—consisting of all the stars, clusters, and nebulæ visible in the most powerful telescope—had an infinite extension in the galactic plane, though the thickness of the system was finite. His hypothesis is not accepted, though, as will be seen later, the extent of the visible universe is almost inconceivably immense.

A great triumph in dynamical astronomy was accomplished in 1846, when Adams and Leverrier, each working independently of the other, announced the position where a new planet should be found. They had computed this position from the perturbations produced on the planet Uranus by the unknown and unseen planet, and Neptune was found very close to the predicted place. Here was a vindication, if such were necessary, of Newton's law of universal gravitation, and it marked an important stage in dynamical astronomy.

The maintenance of the sun's heat was a problem that exercised the minds of physicists and astronomers, and various theories were proposed to account for it. Among these may be noticed the contraction theory which was suggested by Helmholtz in 1854—a theory which inspired a considerable amount of confidence and which is very interesting, showing, as it does, that developments in one particular branch of science may modify or completely overthrow theories propounded with insufficient knowledge of such developments.

In 1854 Helmholtz proposed the theory that the sun continued to emit light and heat because it was contracting under its own gravitational attraction towards its centre. A stone falling to the earth has its kinetic energy, or energy of motion, converted into heat when its motion is arrested; and in the same way, if the matter composing the sun fell towards its centre by only 140 feet

each year, this would account for the heat emitted by the sun. This process could not, however, continue indefinitely because, with increasing density, and consequently a diminished rate of contraction, the sun would grow cooler, until in the course of a few million years there would not be sufficient heat to maintain life on the earth. In the course of time the sun would cease to be gaseous and would become solid and cold.

In 1862 Lord Kelvin investigated the matter more fully than Helmholtz had done, and concluded that if the sun started contracting from a nebula diffused through an infinite space it could not have evolved sufficient heat to last for more than 50 million years. Here a conflict arose between geological evidence and the theories of the physicist, because fossil remains showed that life had been in existence for hundreds of millions of years. As will be seen later, the geologist emerged triumphant from the controversy, and the much longer time-scale for the existence of the solar system was accepted.

Although Fraunhofer was the first to observe the spectra of the stars, about 1824, it was not till 1859 that the principles of spectrum analysis were established by Kirchoff and Bunsen. In 1863–4 Huggins in England, and Secchi at Rome, both of whom can be considered the founders of modern stellar spectroscopy, studied the spectra of stars, and Huggins recognized the lines of familiar terrestrial elements. Secchi, who examined the spectra of nearly 4,000 stars, divided them into four types, and his classification was the standard for many years. The identification of the elements composing the stars with those found on the earth was a step forward—showing a common origin for the various bodies in the universe. Huggins made use of the spectroscope for many other purposes, not the least of which was to determine the radial velocities of stars—that is, the component of their velocities to or from the earth. In 1876 he introduced the dry-plate process into celestial photography and obtained very promising photographs of stellar spectra. Since then amazing developments have taken place in this branch, and the stars have thus yielded up secrets to the physicists that would otherwise never have been divulged.

In 1887 two American physicists, Michelson and Morley, conducted experiments to detect the assumed ether drift as the earth moved round the sun with a velocity of about 18½ miles per second. If there had been such a drift, the velocity of light would not have been the same if it were emitted in the same direction as the earth's orbital motion and at right angles to this direction. It was found that the velocity of light was the same whatever the direction of emission—a discovery which had a profound effect on future developments in our conceptions of the universe. A brief reference will be made to this later when we deal with Einstein's theory of relativity.

In 1894 Percival Lowell, the famous American astronomer, established the Lowell Observatory at Flagstaff, Arizona, at an elevation of 7,000 feet, and on May 24 he began the study of the planet Mars with the aid of an 18-inch refractor, which was replaced in 1896 by a 24-inch one. Schiaparelli, the Italian astronomer, had previously done a considerable amount of work on Mars, and after his death, in 1910, Lowell was generally regarded as the greatest authority on the planet. He was convinced that the so-called canals were artificial constructions for irrigating the more arid portions of Mars, and in his well-known books, *Mars and its Canals*, and *Mars as the Abode of Life*, he put forward the hypothesis of intelligent life on the planet. Shortly before his death he claimed that every new fact discovered by an examination of Mars at each opposition was in accordance with the theory of intelligent life on the planet. While some accepted his views, English astronomers, on the whole, were very doubtful about the artificial character of the "canals," and in more recent times it has been generally agreed that they are subjective, the eye interpreting natural markings on Mars as if they were more or less continuous and nearly straight lines.

It is now believed that Mars is capable of sustaining life—certainly vegetable life, and perhaps animal life too; but this belief is not based on observations of the canals. Spectroscopic and other evidence indicate that the atmosphere is very tenuous, that oxygen, if it exists there, is extremely scarce, and also that the temperature is low, though not so low as to exclude the possibility of life.

With regard to other planets, it is very doubtful if life in any form exists on Venus, though the conditions are such that vegetable life might exist in a low form. All the other planets are ruled out of the possibility of possessing life. Mercury has no atmosphere; the surface exposed to the sun is extremely hot, and the face which is always turned away from the sun is extremely cold. The major planets—Jupiter, Saturn, Uranus, and Neptune—are very cold and their atmospheres consist of methane and ammonia, which are incapable of supporting life such as we know. Of course, there may be forms of life capable of surviving in such an atmosphere, but here we enter the realm of pure speculation.

For some time it was believed that the earth was practically unique among all the bodies in the universe in being the abode of life, and it was even asserted that relatively few planetary systems existed in connection with other stars. While it may be unique so far as the solar system is concerned, in recent times the view that planetary systems must be relatively few has been rather discredited, and there is no valid reason why thousands of millions of planets belonging to other stars should not be the abode of life. The particular form of life that exists on them must, of course, be a matter of mere conjecture.

Problems of cosmogony have occupied the minds of astronomers in recent times, and Sir James Jeans has given them much consideration, particularly in connection with the origin of our planetary system. His tidal theory, which is too well known to need a detailed description, has an important bearing on the distribution of life throughout the universe. This theory postulates the close approach of a star to the sun, thus disrupting our luminary, the planets being formed from the ejected matter. The probability of two stars approaching each other sufficiently close to cause disruption can be estimated, and Sir James Jeans thinks that only one star in a hundred thousand is surrounded by planets. Within recent times the tidal theory has been shown to contain certain serious flaws, and, while some modifications have been proposed, none of these has proved acceptable. There is considerable doubt whether the tidal theory or any form of it can explain the formation of a planetary system, and other

explanations have been suggested. In these circumstances the view about the relative scarcity of planetary systems cannot be considered valid.

In 1943 K. Aa. Strand, of the Sproul Observatory, Swarthmore, U.S.A., published a short note on the discovery of a third member of the 61 Cygni double-star system. Photographs of very high accuracy, taken at different observatories, showed that there was a small body revolving round one of the two visual components; its mass was estimated to be about 16 times that of Jupiter. While this is rather massive for planets such as we know them, it is much too small to be treated as a stellar body, so that we have here the first discovery of a planetary body outside the solar system. A similar body has been discovered in the binary system 70 Ophiuchi, and the existence of two such planetary bodies[1] in relatively close proximity to the sun suggests that there may be many others associated with stars so far away that their planets cannot be detected at present, and perhaps never will be detected. Observational evidence does not always support theoretical deductions, though it frequently does so, and in the present case it seems as if observation is destined to administer the *coup de grâce* to the tidal theory of the origin of planetary systems. Perhaps such systems may be the rule rather than the exception, and life may be widely diffused throughout the universe.

Within comparatively recent years our knowledge of the immensity of the universe has been enlarged by discoveries regarding the distance of the spiral nebulæ. A spiral nebula, unlike a gaseous nebula, consists of an aggregation of stars numbering many thousands of millions. The Milky Way, or Galaxy, is one such system, and our sun is situated in the Galaxy, not at its centre, but about 30,000 light-years from its centre (a light-year is the distance that light travels in one year, and is nearly six million million miles), and the Galaxy is not spherical, but bun-shaped. Light requires about 120,000 years to cross the longest diameter, and about 20,000 years to cross the shortest diameter of

[1] These planets were not actually observed with the telescope. Their presence was inferred from certain irregularities in the movements of the stars around which they revolved.

the system, which contains 80,000 million stars or more, some much larger than the sun and some much smaller. On the whole, our sun can be taken as an average star both in mass and temperature.

There is another Galaxy, comparatively close to us—the Great Nebula in Andromeda—which is visible to the naked eye. It is the nearest of all spiral nebulæ except one; it also consists of an aggregation of stars, but its dimensions are smaller than those of our Galaxy. The Great Nebula in Andromeda is less than a million light-years distant, and it is believed that when the 200-inch telescope now in construction for Palmolar Observatory, U.S.A., is complete, it will be capable of photographing sixteen

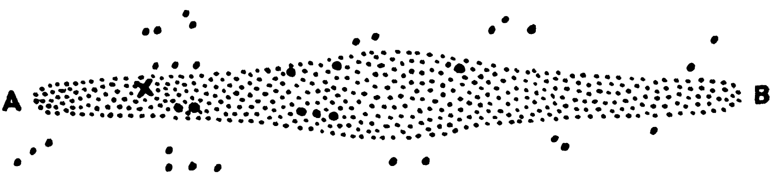



FIG. 11.—A VIEW OF THE GALAXY.

million nebulæ, some of them at a distance of nearly 1,000 million light-years.

In comparison with such immense distances and such vast numbers of stars—all suns like our own, though many are very much hotter and others much cooler—not only the earth but the whole solar system shrinks into a mere speck in the great universe. Every star in any system has its own proper motion, and, in addition, each galaxy has a motion of recession from our Galaxy and from all the others. This is a remarkable discovery (though some think that the effect of this so-called recession can be explained in other ways) and has raised difficult problems in cosmogony.

It should be noticed that the estimated distances of the galaxies depend very largely on the adopted magnitudes of the brightest stars in them, and Hubble assigns an absolute magnitude of $-6{\cdot}3$ to these. But if these objects are not stars, but clusters, globular or otherwise, the true absolute magnitude could easily be four or

five magnitudes brighter, in which case the distances and dimensions of the galaxies would have to be increased about tenfold. The accurate determination of the distances of the extra-galactic nebulæ is a very important and also an extremely difficult problem.

The more distant spiral or extra-galactic nebulæ are running away faster than those that are near, and there is a relation between their speed and their distance. A nebula at a distance of 3½ million light-years has a speed of recession of 330 miles a second, and if the distance is doubled the speed is doubled too. On the other hand, if the distance is only one-half the above figures, the speed of recession is 165 miles a second, and so on. While these results must not be taken as rigorously accurate, they are sufficiently approximate to show that about 1,500 million years ago the millions of nebulæ in the universe were comparatively close or packed together, and that they started expanding and still continue to expand. The speeds of the nebulæ are not, therefore, due to their distances, but their distances are due to their speeds, those which started off with the greatest speed being now at the greatest distance, while those that started off with less speed have not receded so far.

There is abundant evidence to show that the earth was probably separated from the sun—by what process is still in doubt—about 3,000 million years ago, so that the earth is older than the stellar systems, which were closely packed in something like one huge system 1,500 million years ago. This raises a problem for which no adequate solution has yet been found; it is one of the many difficulties confronting the cosmogonist to-day. Evidence from other sources indicates that an upper limit of 10,000 million years should be assigned to the stars, but it is quite possible that modifications in these figures may ensue as a result of further research.

Einstein's general theory of Relativity was verified from observations of the displacement of the light of stars at the solar eclipses of 1919 and 1922. It has also been verified from the shift of the spectrum towards the red in the case of very dense stars like the white dwarfs, such as the companion of Sirius. The anomalies of the motion of the perihelion of the orbit of Mercury's orbit, which had baffled the dynamical astronomer for

many years, were fully explained on Einstein's theory, and it is now generally accepted as a better representation of the behaviour of the bodies in the universe than that obtained from the Newtonian mechanics. The subject of relativity is too abstruse to be dealt with fully in this book, and readers who require information on the theory should consult specialized treatises, of which there are many.

Developments in atomic physics have opened up far-reaching problems regarding the question of Free Will and of our outlook on the universe. Is the universe a closed system, or do recent developments suggest that this view must now be discarded? The present writer has discussed some of these questions elsewhere; [1] it is not possible to deal with them, within the compass of this book, except in a cursory fashion. Towards the end of the present work, some criticism of the views of Professor Whittaker will be offered, with a brief account of the impact of recent discoveries on our outlook.

In the next chapter some consideration will be given to the effect of astronomical development on certain tenets of the Christian religion. This may appear to some readers to be a very unimportant subject which has little interest for the majority of people. Nevertheless, there is a minority whose outlook cannot be ignored and who would probably feel, if nothing were said on the matter, that a subject of importance to them had been evaded.

[1] *Free Will or Determinism*, 1937 (Watts).
*The Free Will Controversy*, 1942 (Watts).

CHAPTER XV

# IMPACT OF ASTRONOMICAL DEVELOPMENTS ON THE CHRISTIAN FAITH

THE earth has been displaced from the commanding position that it once held as the centre of the universe, and man—once supposed to be the last and noblest act of creation—no longer holds the unique position he formerly held. It is now admitted that he is the product of an evolutionary process which has been in progress for about a thousand million years, and that, biologically speaking, he is on the same footing as other forms of life. Even life itself, once believed to be a special act of creation and limited to our planet—for the benefit of which, or rather for the benefit of the human family dwelling on it, all creation came into being—is no longer considered unique so far as the earth is concerned. Given favourable conditions on other planets, it is practically certain that life will develop, though the particular form or forms that it will assume must necessarily be a matter of speculation. It is fairly safe to predict that life will be produced artifically in the laboratory in the near future. Admitting that it will be life in its most primitive form, as such it may contain potentialities for evolving into higher organisms under favourable conditions.

The earth has been dethroned from the centre of the universe; the sun has been dethroned from the centre of the Galaxy; and man has been dethroned from the summit of creation. Has all this made any difference to our conceptions of the destiny of man? Can we still regard him as created for a special purpose—to know God and to serve Him—or must we look upon him as merely a product of evolution which has acted more or less blindly, teleological factors being completely eliminated? If so, need we lower our conceptions of the greatness of man and must we modify our views about the attributes of the Creator?

Some may say that there is nothing ennobling in the conception of a Creator whose chief object was the production of the human family; this view has been enhanced in recent times through the

extraordinary aptitude displayed by the "highest act of création" for the annihilation of members of his own species. In the words of Dr. Inge: "There is, I think, something derogatory to the Deity in supposing that He made this vast universe for so paltry an end as the production of ourselves and our friends."

It is trite to remark that profound modifications of our old views on religious and theological problems have come about as the result of developments in astronomy. Of course, advances in other sciences have had a similar result, but our concern at present is with astronomical progress, and we must limit our remarks to this branch. Although the Copernican astronomy has passed into the realm of common knowledge, there has never been a time when the Christian Churches openly recognized the resulting necessity for a complete restatement of their fundamental position. As a consequence there are many who find serious difficulties in a traditional faith which makes impossible demands on their consciences. Many of its tenets are expressed in mediæval language and definitely imply a geocentric view of the universe, and, while it is often affirmed that there is no serious conflict between religion and science, those who make this affirmation are doing so without considering the problem as it affects the more thoughtful adherents of the Christian religion. The issues involved are very complex, and it will be best to deal with each phase separately.

There is no doubt that a primary difficulty confronts many owing to the fact that the founder of Christianity appeared ignorant of anything approaching our modern conception of the universe,[1] and possessed only such knowledge as was current among the peasants of Palestine in his days. This fact is recognized by theologians, and the *kenosis*, or "self-emptying," theory is offered as an explanation for it; though it must be said that this theory has not proved satisfying to everyone who has been disturbed by the obvious limitations in Christ's knowledge of the universe. Bishop Gore, and many others since his time, display no apprehension because of such limitation, and indeed are quite

[1] The substance of this chapter has been presented more fully elsewhere. See *The Heavens and Faith* (Watts; 1936).

prepared to accept it as a necessary consequence of the Incarnation. Dr. Barnes, a man of science and a modernist, is convinced that the progress of science has not forced us to admit that Christ was morally imperfect or mistaken in his view of God or of man's relation to God. He admits, however, that in so far as he was man, his secular knowledge was that of the Galilean carpenter's son (*Should Such a Faith Offend?*).

This view, while acceptable to many, is nevertheless beset with difficulties. Admitting the limitations in Christ's knowledge about our own planet—limitations which no one who reads the Gospels with an open mind can deny—it is clear that this circumscribed view had a profound effect on certain parts of his teaching. Thus it seems certain that he believed he was the expected Messiah, not only come to earth to establish the Kingdom of God, but also destined to come again "with the clouds of heaven" (St. Mark xiv, 52). The early Christians eagerly looked forward to this second coming, and even St. Paul himself was convinced at one time that it was imminent. His first letter to the Thessalonian Christians shows that he expected Christ to return soon, and the people who were influenced by his view lost nearly all interest in mundane affairs. In a later letter, however, he corrects his earlier impressions and informs the Thessalonians that he never taught that the day of the Lord was about to dawn. Before the second coming there would be an apostasy, a revelation of "the man of sin; the son of perdition," who would not only assume equality with God, but would sit in the temple of God. Many interpretations of "the man of sin" have been given, and various historical monsters have been credited with possessing his attributes.

Down through the ages men have looked for the second coming, and even to-day there are many who expect it to be literally fulfilled. In this connection it is interesting to note that Whiston, who translated Josephus and succeeded Newton as Lucasian Professor of Mathematics at Cambridge, ordered his coach to take him to Jerusalem that he might meet the millennium. Since Whiston's days equally extraordinary measures have been adopted to witness the second coming.

We cannot but deplore the fact that the delusion about the second coming, though not entirely due to the founder of Christianity, was nevertheless fostered by him, and accepted by the Church. It is certain that if he had possessed a more comprehensive view of the world, and had had an inkling of the Copernican system, he would not have advocated views which were consistent only with a geocentric flat-earth conception for which even falling stars presented no difficulties. Here we find it difficult to agree with Dr. Barnes when he asserts that the progress of science has not forced us to admit any mistakes in Christ's views of God or of man's relation to God. How can we draw a sharp line of demarcation between secular knowledge and spiritual revelation? We are often painfully aware of the fact that limitations in the former imply serious limitations in the latter, though it need not necessarily be so; indeed, in some cases the spiritual faculties do not appear to have been eclipsed, or even obscured, by lack of secular knowledge. On the whole, however, such cases are very exceptional.

Professor Leonard Hodgson, in *And Was Made Man*, deals with this subject of secular and spiritual attainments and gives his conclusions as follows:—

> We can no longer, then, draw a distinction within the sphere of the subject-matter presented to our Lord's mind, divorcing what was known and believed in His days about matters of history and science from what was known about God and His Messiah; we cannot say that for one class of material there was a way into His mind through ordinary human channels, while for others there was not. We must honestly acknowledge that even such an idea as that of His own pre-existence might have come to Him from current teaching about the expected Messiah. Here, as in the case of His moral teaching, we must look for evidence of His divine insight, not, as it were, in an account of celestial history and geography revealed by a visitor from above, but in the reaction of his mind to the teaching He happened to meet through His being born and growing up in Palestine

at the beginning of our era. Once again it is to be emphasized that this is not to deny the divine nature of Christ.

When we come to deal with the moral precepts of Christ we are sometimes painfully aware of the extent to which eschatology (the doctrine of last things) coloured his view of human relations. If any of us at present believed that the world was to come to an end very soon and a new order was to be established, it is certain that such a belief would have a great influence on our relations with other people. Reference has already been made to the early Christians in Thessalonica who had taken excessive interest in unfulfilled prophecy and eschatological speculations, so that many neglected the performance of ordinary simple duties. In such conditions it might be easier than it is under a stable social structure to turn the other cheek to anyone who smote us on one cheek, or to give our cloak to those who took away our coat. For this reason the so-called " Sermon on the Mount " (it is almost certain that it was not a sermon delivered at one time and place, but a series of precepts uttered in various circumstances and afterwards collected into the form of a discourse) presents a number of moral paradoxes. In the words of Dean Matthews (in *Christ*), they not only condemn a brutal society; they condemn every society that has existed or that ever could exist. It is quite impossible to construct a society based on some of these precepts, which, if carried out, would encourage impostors, violence, and highway robbery. Of course, not all the precepts laid down for our guidance are of this character, and it may be remarked that a great many are not original, but are paralleled in the Old Testament and the Talmud, while some of them are very similar to the sayings of Buddha.

The urgency of the problem as Christ saw it is manifest from the records given in the Gospels, more especially in the Synoptists—that is, in the first three Gospels. When the Twelve were sent out on their mission they were reassured even if persecution should arise, because, although they were to flee into the next city in such circumstances, they would not have gone through the cities of Israel " till the Son of man be come " (St. Matthew x, 23).

We know nothing about the result of this mission, but St. Luke describes the appointment of seventy others who went out in twos to various places where Christ was to follow later (x, 1). When they returned, with joy, the chief result of their mission seems to have been the casting out of devils, and on learning this Christ informed them that he saw Satan fallen as lightning from heaven—a remark which has been interpreted as referring to a bright meteor or a fireball, the nature of which was unknown in the days of Christ.

From the days of the early Church up to recent times the most fantastic doctrines have originated as a result of the belief in the second coming, and it is very unfortunate that many hymns are still retained which teach this view almost in its old form. Take, for instance, one of the Advent hymns which is still in use, though it is doubtful if anyone takes it literally:—

> Great God, what do I see and hear
> The end of things created;
> The Judge of all men doth appear
> On clouds of glory seated;
> The trumpet sounds, the graves restore
> The dead which they contained before;
> Prepare, my soul, to meet Him.

The view that there would be an actual and visible second coming, which prevailed in the early Church, gradually faded into the background, and even in the case of St. Paul we find that his views on the subject underwent a great change. When St. John's Gospel—the latest of them all—came to be written, the Christians were not so eager about the Day of the Lord as were the early Christians; hence this Gospel contains very little about the signs and wonders which it was once supposed would accompany this consummation. Instead of the former catastrophic view of the end of the old dispensation and the inauguration of the new, the writer of the Fourth Gospel presents us with a picture of the Church under the guidance of the Holy Spirit, and the second coming is regarded as a gradual process. This is actually the view now prevailing among more thoughtful Christians who do not take seriously the passages of Scripture or the hymns which describe the catastrophic end. Nevertheless, the old view still

survives and in particular among some peculiar sects, such as the Seventh Day Adventists, Four Square Gospellers, and others of a similar type. It does not appear, however, that many people at present are concerned with the subject, and it is very largely evaded in Christian teaching because it presents almost insuperable difficulties to thinking people and is a stumbling-block, rather than an asset, to the Christian religion.

Among other modifications induced by astronomy in people's views, reference may be made to the conception of the three-storey universe, heaven being on the top floor and hell occupying the lowest portion. Although no one to-day would take seriously such a conception, people often forget that the abandonment of this view has had an important influence on certain tenets embodied in our Creeds. When we speak of the Ascension it is usually accepted that there was a literal and visual ascension of Christ's body into heaven, and indeed this view is supported by the account given by St. Luke in the opening chapter of the Acts of the Apostles. Not only were the disciples rebuked by the two men in white apparel because they stood looking up into heaven; they were assured that in the manner Christ was received into heaven, so he would come again from heaven. Recognizing, as we now do, that heaven and hell cannot be localized above the clouds or below the earth's crust, what interpretation are we to give to the account of the Ascension?

Dr. Inge, in one of his works, tells a remarkable story in connection with this. He reviewed a book which had been written by a modernist who was not quite satisfied with the usually accepted view of the Ascension, and made some comments approving the views set forth by the author. On reading the review the author was a little perturbed at the thought that he had gone too far with his explanations, and wrote to Dr. Inge assuring him that he was mistaken about his conception of the Ascension. He added that he believed the body of Christ went up for a considerable distance into the atmosphere—a remark which elicited some caustic comments from Dr. Inge in his book where he tells the story.

Can such evasions and equivocations be tolerated indefinitely?

Either the Ascension took place as recorded by St. Luke or it did not so take place. Did the disciples actually see the body rise in the air and disappear into a cloud, and did the two men speak to them and say what St. Luke alleges they said? One would like a definite pronouncement on this subject from our leaders in theological restatement, and although such has been offered in a few cases, it is to be feared that their views have not made much impression and have met with serious opposition. It is incumbent on the Bishops of the Church of England to take the lead in such matters; but too often they leave the initiative to others, whose pronouncements, when they appear, are subject to severe criticism. Although bishops and the inferior clergy have shown themselves reactionary in such matters, the laity cannot be exonerated from responsibility.

It is scarcely necessary to point out that modifications in our views of the nature of the Ascension would introduce profound modifications in other doctrines, and therefore would have far-reaching consequences. Indeed, this is one reason why many are so reluctant to alter their method of statement of certain tenets. To do so would compromise their basic position and render it almost untenable. It is often believed that mediæval views of the universe are specially propitious for supporting Catholic doctrine (by Catholic is implied not only Roman Catholicism, but also Catholicism as understood in a certain section of the Church of England), but this is a one-sided view. It is true that such views lend support to the Catholic in certain dogmas, but they also render assistance to the non-Catholic in other ways. For instance, the belief in the literal second coming, such as was accepted by the early Christians, is necessary to the Four Square Gospellers, who would scarcely call themselves Catholics. Among Fundamentalists, of whom more are found in America than in this country, verbal inspiration of Scripture and its literal interpretation are essential. How they reconcile the cosmogony of Christ with this view is difficult to explain.

Much could be said about the indirect effect of the eschatological views of Christ. Thus it has been argued that he forbade

the use of force in any circumstances; as a result we have the difficult problem of the ultra-pacifist and the conscientious objector. They can always cite Scripture in support of their attitude, and their conflict with the civil authorities has been the cause of a considerable amount of embarrassment and trouble in recent times. Then we have also the problem of the reformer in our economic system who proves conclusively, to his own satisfaction, that Christ was a Communist and that no other economic system can be regarded as Christian. A number of the clergy both of the Church of England and among Nonconformist bodies have associated themselves with these movements. Some have deliberately set out to enrol men who pledge themselves not to take part in warfare in any circumstances, even if their country is invaded. Others have been active in propagating the advantages of a Communistic State, the justification for which they find in the New Testament. It may be admitted that there is much in the teaching of Christ—if we are prepared to believe that we have his *ipsissima dicta* recorded by the Synoptists—to lend support to these views, and it is very difficult to argue with people who advocate such extreme doctrines.

The opinion of the present writer is that it is extremely risky to base any system, economic or otherwise, on the teaching or supposed teaching of Christ, because, even if we have an accurate record of his sayings—which is far from being true—we must recognize that his outlook was coloured by eschatology. Albert Schweitzer has dealt with this subject in his *The Quest of the Historical Jesus*, in which he explains Christ as one who was obsessed with the thought of the last things, being under the influence of Jewish apocalyptic writers. While Schweitzer went rather far and was a little one-sided in his treatment of the Gospels, we are indebted to him for emphasizing the importance of the apocalyptic background of Jewish thought in the days of Christ. It is scarcely necessary to remark that this background was largely the result of current astronomical views.

In *The Church in the World*, Dr. Inge points out that there are three positions which the Church may adopt in dealing with astronomical development. The first is to condemn modern

astronomy as impious and heretical—a view which neither Dr. Inge nor anyone else could seriously entertain. The second is to admit that traditional doctrines do not belong to the natural world with which science deals, but that this does not necessarily deny that they may possess a higher truth outside the reach of science; they may be regarded as symbolic of eternal truths, or, in Dr. Inge's words, " aids to the imagination in forming clear conceptions of revealed truth in a region beyond the compass of our senses." We agree with Dr. Inge that such a disparagement of science may lead to a denial of the objective existence of the universe, and this will not help us very much.

The third policy advocated, with which we fully agree, is to recognize the necessity for recasting all theological doctrines which rest on the geocentric theory of the universe. Dr. Inge realizes the seriousness of such a step and also the difficulty in taking it, but he believes that anything is better than trying to conceal an open sore which destroys our joy and peace in believing. We wish that he had dealt fully with some scheme for recasting the theological doctrines; perhaps such a scheme might have more far-reaching repercussions than he allowed for.

There is another matter, closely associated with Christian theology, which requires some consideration because astronomical developments have tended to modify people's views of the subject —the Fall, as narrated in the third chapter of the Book of Genesis. Very few accept this story as literal history, but many have attempted to give it a spiritual and allegorical interpretation, and some have even held the view that there was a Fall before our planet was inhabited. The name " Pre-mundane Fall " has been applied to this supposed Fall, which appears to have been suggested by Origen and which has been revived in comparatively recent times. A number of writers on theology have dealt with it, but it will suffice if a résumé of the arguments propounded by Canon Peter Green are considered. These will be found in his recent work, *The Pre-Mundane Fall*, in which he admits that the Church must either frankly and explicitly surrender the doctrine of the Fall, or it must seek some approach to the doctrine which will bring it into harmony with the whole corpus of modern

knowledge. His inquiry can be summarized under three headings, each of which will be considered separately.

(1) *What was the Nature of Unfallen Man?*

First of all we start from the statement that man was created in the likeness of God; and even if no such statement occurred in Holy Writ we should still be forced to postulate a resemblance between divine and human nature. This likeness is necessary for any rational system of morals, because there can be no moral obligation on men to obey a law imposed on them from without. Assuming that likeness to God is men's true nature, and assuming that they are able to attain to it with his help, we have an explanation of the categorical imperative "Thou shalt," and also a firm basis for ethics. In addition, the possibility of an Incarnation depends on some likeness between divine and human nature. On these grounds Canon Green is led to formulate the following conceptions on Divine Nature and Human Nature:—

> Divine Nature. Three centres of Knowledge, Will, and Affection in a Unity of Nature in such a way that the whole NATURE is in each person. "One God in Trinity, and Trinity in Unity; neither confounding the Persons nor dividing the Substance."
>
> Human Nature. Created in the likeness of God; many centres of knowledge, will, and affection in a Unity of Human Nature in such a way that the whole Nature was in each person.

The creation of such a Human Nature would, Canon Green thinks, involve the creation of a universe; and the entire universe is the expression, the manifestation, of a single spirit. Theology owes much to Darwin for showing us that man is inseparable from the entire universe, and before mankind suffered from the effects of the Fall such a universe would be "all very good."

(2) *What was the Fall?*

The character of the unity of God is neither a physical nor a mechanical unity, and hence it must be a moral unity—the unity

of love. The nature of the Fall was the assertion of the Individual against the Unity, and the result on the universe was to shatter it into fragments. There would be no possibility of the fragments coming together again unless God the Holy Ghost, the Creative Spirit of God by whom man was first created, had performed a new creative act and created a new human nature.

How is it to be made sure that the new nature shall not also fall and be shattered? This is done through God the Son, who became the Second Adam, and here we see the need for, and purpose of, the Incarnation. This new nature must be hardened against temptation in the only way by which free spirit can be hardened—by victorious resistance. Here we see why Christ was tempted like mankind, yet without sin, and we see also the necessity for the Cross, because created, God-dependent spirit needs perfect submission, perfect and loving surrender, to God.

The Incarnation has a universal or cosmic significance. The disruption of human spirit in the Fall involved the shattering of the universe, and there would not be any principle of order by which such chaos could be overcome. However, the creation of a new humanity would supply a centre for a new universe and the power by which it could be attained, and the process of unification is in evidence in evolution, which may be described as "a continuous striving after ever greater and richer diversity in more and more perfect unity." This striving after unity is displayed not only in the material universe, but also in the mental and spiritual world:—

> In the sphere of the intellect, all advance in knowledge aims at our all thinking alike. In the sphere of the will, all advance in morals has as its aim that we may all will the same ends. In the sphere of the affections, the aim and purpose of art is that we may all share the same emotions.

(3) *What were the Results of the Fall?*

It will be better to answer this question in the summary given by Canon Green:—

> . . . each man, instead of being a creature whose nature was love and who had the whole of human nature to function

through, became self-centred, self-seeking, and shut up in the narrow limits of mere individuality, with but a poor fragment of human nature at his command.

Various arguments are adduced in favour of the doctrine. The first of these is based on the fundamental difference between the attitude of Eastern and Western men towards the idea of a future life. The Eastern man longs to be delivered from the burden of individual life, and the unity lost in the Fall and regained in Christ meets his desires, promising him the rest and peace of Nirvana, but a rest and peace of which he can be conscious. To the Western man it promises personal immortality and fulness of life, in place of the narrow boundaries of mere individuality. The fact that the view of the nature of the Fall reconciles these two conflicting desires of two divisions of the whole of humanity should count for something, according to Canon Green. (Nothing is said about the views of the coloured races in Africa who number about 50 millions.)

It is unnecessary to deal fully with some of the other arguments in favour of Canon Green's theory of the Fall, such as the existence of morals, mystical experience, etc. The last and chief item of evidence for the Pre-Mundane Fall cited by Canon Green is the fact that without it there seems to be no foundation for the dogmatic system which the Catholic Church offers to mankind. If, on the other hand, the doctrine of the Pre-Mundane Fall is accepted, " the whole of God's ' plan of salvation ' is seen to be necessary, and Christianity is seen to offer the only really satisfactory philosophy of life."

If the nature of unfallen man was really a multiplicity of souls in a unity of nature, and if the Fall was an assertion of the individual against the unity, the whole scheme of Christian doctrine necessarily follows. A new humanity is created to take the place of the first humanity, and, to obviate a second Fall, this new nature must be assumed by God himself, so God the Son became our Second Adam. The doctrine of the Second Adam, if it does not make the Virgin Birth necessary, at least shows it to be highly congruous.

Canon Green finishes his work by expressing the opinion that the Church will surely accept the idea of the Pre-Mundane Fall, and then " she will be in a position to address herself to the great task of harmonizing all knowledge in one coherent system under the guidance of Theology, the Queen of the Sciences."

It is extremely difficult to criticize this doctrine in detail because it erects an imposing edifice on a foundation which consists of pure speculation. The doctrine is devoid of any historical basis and cannot be submitted to scientific examination. Of the two alternatives suggested—the surrender of the doctrine of the Fall, or the approach to it in such a manner as will bring it into harmony with the whole corpus of modern knowledge—it is highly probable that most people will prefer the former. If the interpretation given by Canon Green is the best available, and if without such interpretation there is no foundation for the dogmatic system which the Catholic Church offers to mankind, many people will feel apprehensive about the future of the Catholic Church. Indeed, it would not be going too far to say that the naïve account of the Fall as recorded in the third chapter of Genesis is by far to be preferred to that suggested by Canon Green. It would be outside the scope of this book to criticize the doctrine from every scientific point of view, as we are concerned primarily with the astronomical outlook, but a few brief remarks on certain aspects of the problem will not be out of place.

The postulate of the resemblance between the divine and human nature is stated to be necessary for any rational system of morals. Canon Green overlooks the important fact that other species besides *Homo sapiens* have their system of morals, which, in a great many cases, is most carefully observed. It is beside the question to argue that their system is not the same as ours; from their point of view their system may be much higher than ours. It is difficult to discover why certain species conform to standards which, so far as we know, have little or no survival value for the individual or the species. We need only refer, as an example, to monogamy, which exists among some of the " lower " forms of life. The assumption that likeness to God is man's true nature appears to rule out other forms of life from this

likeness; nevertheless, later on we are assured that if man is spiritual "the whole universe is spiritual." If the latter statement is true there must be some likeness between God and all His creation—including every form of loathsome parasite or microbe that destroys human life. This aspect clearly requires further elucidation.

When the Individual asserted himself against the Unity, and the result on the universe was "to shatter it to fragments," what is implied by these last words? Was it a physical or a moral shattering? From the assumption that a new human nature was created and was delivered from the possibility of another fall with disastrous consequences, the means of deliverance being through the Incarnation, it would seem that the shattering was moral, not physical. Later on, however, we are led to believe that there must have been some kind of physical shattering as well. There was no principle of order by which the resulting chaos could be overcome, but the creation of a new humanity would supply a centre for a new universe. The remarkable statement follows that the power by which this new universe could be attained, and also the process of unification, is seen in the process of evolution. The striving after unity is displayed in the material universe as well as in the realms of the mental and spiritual, so presumably there was some shattering of the material universe; but no details are given which help the reader to visualize what this "shattering" really implied. It is asserted that evolution is "a continuous striving after ever greater and greater diversity in more and more perfect unity," but this is a hypothesis which has little or no support in the realm of biology.

The "arguments" brought forward in support of the doctrine are so weak that they scarcely require comment. The first of these, which attempts to show the reconciliation between the views of the East and those of the West, cannot be taken seriously, and the same may be said of the last and chief evidence for the Pre-Mundane Fall. Without such a Fall there seems to be no foundation for the dogmatic system which the Catholic Church offers to mankind; but must we be prepared to accept any grotesque theory if, by doing so, we can support the claims of the

Catholic Church? If the answer is in the affirmative it is unnecessary, and indeed practically impossible, to discuss the matter farther.

From the astronomical point of view the great difficulty of the doctrine is the lack of any time scale. There is no indication of the period in the history of the universe when man was unfallen or when the Individual asserted himself against the Unity. Canon Green points out the absurdity of supposing that the faulty moral choice of a single pair of human beings on our planet was the cause of all the pain of the universe, but it does not simplify the problem very much to push it back in time to the period, whenever that was, in which the Individual asserted himself against the Unity. We may anticipate Chapter XVIII and ask whether this took place before the universe started expanding, and whether it was the cause of the shattering of the universe into fragments, this "shattering" appearing in the initial stage of the expanding universe and being still obvious in the recession of the spiral nebulæ. If Canon Green thinks that this so-called shattering of the universe is the outcome of the rebellion of the Individual against the Unity, he may be assured that he will not find favour for his view among astronomers.

Another great difficulty arises when we consider the object of the Incarnation. Its purpose was to make certain that the new nature should not also fall and be shattered. But the Incarnation was an event comparatively late in the history of the human family, which is almost certainly at least 200,000 years old; so we might infer that for less than 2,000 years (or about one per cent. of the period of the existence of the human family) has *Homo sapiens* been assured that he will not suffer a Fall and be shattered. Was this assurance denied to the people of some of the old civilizations, and did any of them suffer from a shattering effect? It would assist readers very much if Canon Green clarified some of these points, the obscurity of which detracts considerably from the reasonableness of his views.

Finally, Canon Green's question about the solicitude of God for man—"Can astronomers show us anything in the universe as worthy of God's love as man?"—can be answered very simply

by saying that astronomers, *as astronomers*, are not in the least concerned about God's solicitude for man, or indeed for anything else. As an individual each one may hold his own views on the subject of God's care, but as an astronomer it does not enter into his province to make any definite pronouncement on the matter. Astronomers to-day believe that there are planetary systems associated with many of the stars (see p. 137) and also that the existence of life on some of these planetary systems is quite probable. They do not think that God has any more solicitude for the forms of life on these planets, whatever the forms may be, than He has for human beings on this planet. Very few astronomers would agree with Canon Green when he propounds and answers the question regarding God's aim and purpose in the creation of the universe. He is firmly convinced that man is this aim and purpose, but many astronomers would prefer to answer in the words of Sir Arthur Eddington, who was by no means a cynic. Speaking of the lack of the purifying protection of intense heat, or the equally efficacious absolute cold of space, he describes man as "one of the gruesome results of this occasional failure of antiseptic precautions."

## CHAPTER XVI

# SIR EDMUND T. WHITTAKER ON COSMOGONY AND RELIGION

A REMARKABLE anomaly has arisen in comparatively recent years regarding Christian apologetics. A number of official representatives of the Christian faith—that is to say, the clergy who are ordained to uphold the tenets as laid down in the Thirty-nine Articles and the Creeds, and are pledged to be ready, " with all faithful diligence, to banish and drive away all erroneous and strange doctrines contrary to God's word "—have shown themselves prepared to criticize many of the doctrines of the Church. On the other hand, we find a tendency among some men of science to range themselves on the side of orthodoxy and to display a greater solicitude for banishing " erroneous and strange doctrines contrary to God's word " than do some of the clergy. It is scarcely necessary to say that pronouncements in support of the Christian faith from men of science are eagerly laid hold of by the orthodox to confirm their position, though it must be admitted that in some cases the apologetics of men of science have done more to weaken than to strengthen the Christian position.

In the present chapter we shall outline the attitude of a well-known man of science—Sir Edmund T. Whittaker, Professor of Mathematics in the University of Edinburgh. His views are embodied in the Riddell Memorial Lectures delivered before the University of Durham in February, 1942, and later published in a small book.[1]

In the first lecture—" What is Permanent in Nature?"—Whittaker points out that there is a difference between the domains to which dogmatic religion and physical science are related. (Physical science is now so closely related to astronomy that we do not propose drawing a sharp line of demarcation between them.) The physicist concerns himself with occurrences, each of which

[1] *The Beginning and End of the World.* By Edmund Taylor Whittaker, F.R.S., Sc.D., LL.D. (Oxford University Press; 1942.)

not only happens at some definite time and place, but is capable of being repeated, and hence can be made the subject of prediction. Investigations of physical occurrences lead to the discovery of "laws of Nature" which, until recently, were supposed to be invariable and eternal. So long as we limit ourselves to calculating the connection between these laws and the consequences of their operations, we can ignore all issues outside this field, particularly those of theology. Thus the material universe can be pictured as a closed system.

Many things of great importance, however, do not enter into the subject-matter of scientific investigation—for example, freedom of the will and moral responsibility. In addition, even among physical happenings, anything which is truly unique is outside the province of science. Among unique happenings reference is made to the Creation, of which science can give no account. Though we can trace the development of the material universe backwards in time, we ultimately arrive at a critical stage beyond which the laws of Nature, as understood by us, cannot have operated.

If we agree to remain within the purely scientific circle of ideas, we may regard the world as a mechanism, "functioning in a regular order under the rule of timeless laws," but this representation ceases to be valid at the birth and extinction of the universe; therefore these events can be understood only by those aspects of reality which are interpreted by religion.

It is admitted that the outlook of the non-religious man on religion is very much dominated by ideas derived from the methods and results of experimental philosophy, and that these may induce a frame of mind unfavourable to belief. It is therefore assumed that the influence of science on religion is not logical, but psychological, and an instance of this psychological aspect is found in the knowledge of the insignificance of the earth in the universe. Inhabitants of this planet, realizing that it is a speck in the universe, inquire if a revelation is necessary in such a local affair as our planet, which has so little cosmical importance. Again, propositions of mathematics and physics are accepted by everyone, but no theological system has gained universal assent, for which

reason many would naturally conclude—wrongly, Whittaker thinks—that religion occupies an inferior position to science as regards its mode of demonstration. He maintains that this view is erroneous because the certitude of science is obtained only at the cost of a strict limitation of its subject-matter, being confined to purely logical inferences from observation and experiment. On the other hand, the whole field of reality, as it is envisaged by religious thought, includes the will; hence the conviction of religious truth involves not the intellect alone, but the intellect and the will together.

It is further asserted that belief in theological doctrine is not necessarily less rational than belief in the statements of natural philosophy: "The doctrines of the Church are not vague or doubtful, as compared with the results of science, and the confidence is not less secure." Religions possessing vital force are positive religions, and this implies dogmas and ordinances. Among the dogmas are found solutions of the great problems which have always engaged the mind of man—the nature of reality, the existence of God, the origin of the world, the source of evil, the expiation of sin, the future of humanity.

Science is most closely related to the dogmatic aspect of religion because science, in its own way, tries to answer fundamental questions about the nature of the universe; but its answers are often anti-Christian. For example, it asserts that life and mind are merely forms or accompaniments of matter and energy, and that these are the only true realities. The German natural philosophers of the last century based this doctrine on the principle of the conservation of mass and the principle of the conservation of energy; they assumed that science had proved matter and energy to be eternal. Whittaker believes that this dependence on scientific theories has rendered materialistic Rationalism vulnerable from the side of philosophy and also from the side of physics, and he then proceeds to examine the doctrine of the permanence of matter.

The remainder of the first lecture is devoted to an historical survey of the theories of matter up to recent times. The physicist now asserts that the external world is constituted of entities—

" the corporundals," electrons, protons, positrons, neutrons, etc. These are particles which have no permanent existence, shape, or location, and can be described only by mathematical formulæ which can predict the result of any experiment. " Mechanicism has been replaced by a pan-mathematical conception of the universe." The downfall of the classical physics has led to a change in the attitude of physicists towards philosophical interpretations of the universe, and two well-known English physicists, Sir Arthur Eddington and Sir James Jeans, have favoured a type of subjective idealism. Whittaker conjectures, however, that the view which will finally prevail among men of science will be a dualism, similar to the teaching of the Scholastics.

The second lecture—" The Energy of the Universe and its Degradation "—deals with the well-known law of entropy. This law excludes the possibility of a cyclic world-process. The universe is running down and will eventually attain a state of maximum entropy,[1] when all bodies will have the same temperature and life will end. Since entropy is essentially positive, its increase must have had a beginning—that is, a *creation*. The knowledge that the world has been created in time and will finally die is of great importance for metaphysics and theology, " for it implies that God is not Nature, and Nature is not God; and thus we reject every form of pantheism, the philosophy which identifies the Creator with creation and pictures him as coming into being in the self-unfolding or evolution of the material universe. For if God were bound up with the world, it would be necessary for God to be born and to perish."

Assuming that the universe will perish, can we accept naturalistic humanism as its true interpretation? Whittaker is unable to accept such an interpretation, and argues that it is more reasonable to believe that there is some purpose in creation and that something persists and is immortal. That " something " is man, and indeed the goal of the entire process of evolution and the justification of creation itself is the existence of human personality, which alone in the universe is final and has abiding significance. He goes farther, and asserts that in the eternal

[1] This term is explained in the next chapter.

purpose of God this has been granted so that the individual man, "born into the new creation of the Church, shall know, serve, and love Him for ever."

The third lecture—"The Cosmical Process"—deals first of all with certain relations between known constants of Nature, such as the velocity of light, the radius of the electron, the masses of the electron and proton, the average density of matter in the universe, etc. It is unnecessary to dwell on this particular portion of the lecture because, although such apparent relations open up new prospects in cosmogony, there is still a lack of confirmatory evidence.

Whittaker is on more solid ground when he deals with the age of the earth, which has been deduced from various lines of research, and he accepts the figure now commonly adopted—about three thousand million years. A long discussion on the evolution of the stars follows and various views are examined, but it is unnecessary to deal with these in detail. A life of ten thousand to a hundred thousand million years is assigned to the typical star, a view in accordance with recent research on problems of cosmogony, though the velocities of recession of the spiral nebulæ cannot be reconciled with these figures. Ignoring this difficulty for the present, it is believed that about a thousand or ten thousand million years ago the nebulæ, the stars, and even the earth itself, may have originated almost simultaneously, and according to Whittaker this is the ultimate point of physical science, "the farthest glimpse that we can obtain of the material universe by our natural faculties." He does not think that matter or energy existed before this in an inert condition and was galvanized into activity at a certain instant. It is, he believes, simpler to postulate a creation *ex nihilo*, or an operation of the Divine Will to constitute Nature from nothingness. He thinks that such an idea originated in Christianity alone among all religions, pagan philosophers and even later Jewish writers contemplating an uncreated matter, co-eternal with God, by whose activity it received form.

Christian theology does not limit the act of creation to a particular moment, but regards the process of creation as con-

tinuous. An important distinction, however, is drawn between the primary or supernatural creation—a creation *ex nihilo*—and the subsequent creation—*mediante natura*—the continuous development of the evolutionary process. This distinction guards against the Deistic conception of God, who, having created the world, left subsequent happenings to the fate of invariable scientific laws. The Christian doctrine is that all creation is not evolution, though all evolution is creation.

Whittaker ends his lecture with the following words :—

> Belief in God the Creator is the first article of the Creed, and the foundation of the Faith. The purpose of creation was completed by the Incarnation of the eternal Word, Who was in the beginning with God, and Who was God ; which gave to this small planet the value of the universe, and gave to the narrow span of time the value of eternity. But the doctrine of the Incarnation belongs to revelation, and I have moved within the narrower sphere of the natural reason. The purpose of these lectures has been to maintain the doctrine which the Church has expressed in these words :—
>
> 'Eadem sancta mater Ecclesia tenet et docet, Deum, rerum omnium principium et finem, naturali humanæ rationis lumine e rebus creatis certo cognosci posse.'
>
> 'That God, the first cause and last end of all things, can, from created things, be known with certainty by the natural light of human reason.'

In substance, Whittaker maintains that developments in astronomy, which includes physics and cosmogony, rule out every form of Pantheism and Deism. He does not confine his views to mere negations, however, because he upholds the Christian point of view and is convinced that the purpose of Creation was completed by the Incarnation of the eternal Word, and that this gave to our planet the value of the universe. Speaking of the extent of the universe, he says that our Galaxy is one of hundreds of millions of similar aggregates of stars, and adds: "For a parallel to such a combination of seeming insignificance with

latent majesty we can only think of the Child laid in the manger of Bethlehem."

It is not our purpose to enter into theological controversies, and for this reason it will be better if we offer no criticism of the views regarding the implications of the Incarnation. Other points raised in the Lectures are of more fundamental importance, and these will now be dealt with.

CHAPTER XVII

# THE SECOND LAW OF THERMODYNAMICS AND THE BEGINNING OF THE UNIVERSE

BEFORE examining the main points in Whittaker's argument it may be remarked that he adopts a very arbitrary method in excluding certain things from the realm of science. In the opening chapter he tells us that there are many things which do not enter into the subject-matter of scientific investigation, and among these are mentioned freedom of the will and moral responsibility. It is, to say the least, very remarkable that a man of science should commit himself to such a statement, which does not stand the test of a critical examination, as the following considerations will show.

Most people to-day are aware of the important part played by hormones—the secretions of the ductless glands—on people's characteristics, physical as well as mental. The failure of the thyroid gland to function properly, which is responsible for the disease of cretinism, can be counteracted by doses of the extract prepared from the thyroid gland. The unhappy victim may not always be responsible for his actions, and the moralist can do little to alleviate his condition. It is not too much to say that the chemist, in these circumstances, can often do more in changing the character of a person than can the moralist. Diseases due to the lack of certain vitamins, such as beri-beri, scurvy, rickets, pellagra, etc., are amenable to treatment by the chemist, and in the case of pellagra, where insanity sometimes occurs, questions of moral responsibility or lack of moral responsibility decidedly arise. Incidentally it may be pointed out that the administration of a sufficient dose of nicotainamide—a derivative of nicotine—in the food of those suffering from pellagra very quickly brings relief to the victims, whose diet has been lacking in this important vitamin.

If temperaments depended entirely on the secretions of the ductless glands, science would be able to change people's physical

and mental nature; but it is probably too much to assume that the mental traits are solely dependent on the hormones. In this connection some reference may be made to the work of the psychologist, which is recognized as a very important asset in dealing with certain pathological cases. There are those unfortunate subjects who find it impossible to adjust themselves to the social environment, and in many cases such maladjustments cannot be attributed to a disturbance in the endocrine secretions. The psychologist is often able to render very valuable assistance where other methods are useless, and instances of such assistance are so well known that it is unnecessary to refer to specific cases. It must not be assumed, however, that the work of the psychologist must be relegated to some realm other than the scientific. In certain respects the method adopted by the psychologist is just as scientific as is that of the food chemist, and it is utterly unreasonable to say that freedom of the will and moral responsibility do not enter into the subject-matter of scientific investigation. Those who have studied Westermarck's works are aware that even the nature of moral law has been subjected to scientific investigation by sociologists. Whittaker's exclusion of freedom of the will and moral responsibility from the subject-matter of scientific investigation has no justification.

Whittaker is on much firmer ground when he deals with the second law of thermodynamics in the second chapter, and this subject requires some elucidation. The first law of thermodynamics teaches us that there is equivalence of heat and mechanical work and that energy is indestructible. We can change energy from one form to another, as in the case of striking an anvil with a hammer, where the energy of motion of the hammer is converted into heat and sound, while the total amount of energy remains unaltered. It embodies the principle of the conservation of energy, and here we include the whole universe, the total energy of which, though manifesting itself in many forms, nevertheless remains constant. When we see a meteor—commonly known as a "shooting star"—we see a tiny speck, generally much smaller than a grain of shot, whose energy of motion is converted into energy of light and heat. The speck

strikes the upper regions of the earth's atmosphere with a velocity which may be anything from 10 to 45 miles a second, and the enormous amount of kinetic energy possessed by the small particle is converted in a few seconds into other forms of energy—light and heat. All through the universe there is a continuous process of transformation of energy from one form into another. We might, indeed, think that such a transformation could go on for ever, but this view is not generally accepted.

The second law of thermodynamics, advanced by Clausius in 1851, tells us that heat cannot of itself—that is, without the performance of work by some external agency—pass from a cold to a warmer body. In 1852 William Thomson (Lord Kelvin) enunciated the law in a different but equivalent form—namely, that a periodically functioning machine cannot continue to perform work by drawing heat from a reservoir. For example, we cannot use a body as a source of energy—say to operate an engine—by cooling it below the temperature of its surroundings.

The importance of the second law of thermodynamics is seen when the principle is applied to the astronomical universe. Energy in the interiors of stars is liberated far down beneath the surface as quanta of very short wave-length, but by the time these quanta, which have high energy, emerge at the surface of the star, the wave-length is longer. When the quanta encounter dust-particles, or even stray atoms or electrons in space, the wave-length of the radiation is further increased. Hence energy of high frequency is being continuously transformed into energy of lower frequency (heat energy), but the reverse process does not go on. If it did we should expect cyclic processes and there would be an eternal reiteration, in which case the life of the universe would continue for all eternity. The case of the meteor previously mentioned illustrates this point. Friction with the atmosphere is responsible for converting mechanical energy into heat and light, but it is not possible to convert all that heat and light back again into mechanical energy, though some of it can be so reconverted. There is a physical law of irreversibility which makes complete recovery impossible, and the energy of the

universe, on the whole, is suffering degradation and cannot return to its original state.

There are apparent exceptions to the law, but, as will be seen, they are special and local cases which do not affect the working of the law generally. When we burn a piece of wood, peat, or coal, we produce light as well as heat; but, in accordance with the law, we should obtain heat and not light, because light-waves are of higher frequency than heat-waves. How has the original energy supplied by light been emanated as light again? To answer this question it must be remembered that the energy stored up in vegetation, coal, peat, or even more recent vegetation, is primarily energy resulting from the sun's light, or even from radiation of higher frequency than ordinary light. When we burn the vegetable matter we get the energy in the form of both light and heat, but the amount of energy due to light is considerably less than that originally put into it by the sun. On the other hand, the amount of energy due to heat is very much more than that originally supplied to it as heat by the sun, so that, taken on the whole, the tendency has been for a transformation of energy from high to low frequencies.

Obviously this transformation cannot continue for ever, and the amount of energy available for keeping the universe going is steadily decreasing. Imagine a water-mill driven by water contained in a reservoir which does not receive an extraneous supply. In time the reservoir will have emptied itself and no more energy will be available for useful work—a dead level has been reached and the mill-wheel is silent. In the same way we can also imagine all the matter of the universe transformed into radiation, when a uniform temperature—a dead level—would prevail everywhere, though it is not necessary to go quite as far as this and to postulate radiation without matter in a universe which has reached a dead level.

Not all the matter in the universe need be transformed into radiation. It is believed that the sun will increase in temperature for many thousands of millions of years, until life on this planet will be exterminated. Then, when all the hydrogen content of the sun has been transmuted into helium, no more fuel will be

available to supply the energy, and the sun will contract and will shrink until it emits only a fraction of the light and heat that it formerly emitted. Afterwards it will collapse into a white dwarf, and will finally become a cold body, from which state there will be no resuscitation unless, by a very small chance, it collides with another star.[1] Failing this remote possibility, it would reach the stage that all stars will reach in time, when their temperatures and that of space will be the same—a very low temperature, because space has such an enormous capacity for absorbing heat. When this condition has been reached we can speak of the death of the universe, no more useful energy being available, though the total energy would be just the same as it is to-day or as it was thousands of millions of years ago.

The above principle can be expressed by the use of the concept of *entropy*, introduced by Clausius. Entropy may be described as the unconsumed energy which is not available for mechanical work at any time. In the words of Sir Arthur Eddington, it can also be described as a measure of the disorganization of a system. He gives examples of natural processes which break up an organized system into a random distribution (*New Pathways in Science*, Chapter III). Thus, when plane waves of sunlight travelling in one direction fall on a white sheet of paper they are scattered in all directions, and, as the direction of the waves becomes disorganized, there is an increase of entropy. If a solid body is moving as a whole, its molecules travel together, but when it encounters another body the molecules begin to move indiscriminately in all directions. Although the heat produced by the impact is the equivalent of the lost energy of motion of the body, it has a less organized form. Many more instances will occur to the reader, and there is a continual wastage of organization (not of energy, which is simply changed into another form) going on in the universe. It must be remembered, however, that heat, when concentrated, is not fully disorganized energy, because a further decrease of organization takes place when the heat diffuses evenly to bring the body and its surroundings to the same temperature.

[1] See p. 199.

The entropy of the universe is increasing, but this increase could not have continued for an indefinite period, and hence must have had a beginning at some period. This period is identified by Whittaker with creation, when the entropy of the universe was less than it has ever been subsequently. There is an apparent contradiction between the accounts of the world-process as given by the physicist and the biologist, but it is only apparent. The physicist asserts that the entropy of the universe is continually increasing, and this can be taken to imply an irreversible movement from order to disorder. The biologist asserts that, on the doctrine of biological evolution, the trend of secular changes is in the direction of the more complex and of higher organization. But the physicist is speaking of the universe as a whole, while the biologist is limiting his view to occurrences on the earth—a mere speck in the cosmic universe. Such eddies may reverse the direction of the main current, but they are relatively small, and also of relatively short duration. The biological view does not alter the fact that the world-process must end finally in death.

Whittaker believes that the certainty that all life on the earth must ultimately be extinguished is fatal to many widely held conceptions of the meaning and purpose of the universe. In particular, it is fatal to the idea of progress and to hopes for the ascent of man. Mankind in the aggregate has been set up in recent times as the chief object of aspiration, and the humanist philosophy has as its great ideal the carrying forward of society to a splendid future. Whittaker shows the futility of such views and believes that the individual life, not the race, acquires the supreme value when humanity is reached in the course of development.

One is almost tempted to digress from physical science at this stage and to ask Whittaker what he means by "humanity." Probably he would not include *Homo neanderthalensis* in the category, and no doubt the anthropologist would like to know at what stage of development *Homo sapiens* acquired the supreme value for the individual. His extraordinary attainments for mutual destruction, and perhaps for the annihilation of his own

species, cast some doubts on the view of the value of the individual, but this is a highly speculative issue. It will be better, therefore, if we examine the argument—the validity of the second law of thermodynamics—on which Whittaker's views are largely based. If this law does not hold good, a large part of his conclusions must be modified or entirely discarded. If it does hold, then it is difficult to avoid the conclusion that the life of the universe will finally end and, further, that at some period the universe was wound up and started on its career, just as we wind up a clock and allow it to go until the weights have reached the ground or the energy of the spring has been exhausted in driving the machinery.

Before examining more closely the evidence for the second law of thermodynamics it may be pointed out that there are some laws which we accept implicitly when they apply only on a small scale, but which appear to require modification when we deal with the macroscopic universe. One example of this is the principle of the conservation of angular momentum.

Imagine a body rotating about an axis. (To simplify the problem, we shall ignore the effects of friction on the axis or the effects of atmospheric resistance on the rotating body.) Take the mass of any small portion of the body, multiply it by its velocity, and multiply that again by the distance of the portion from the axis. Do this for every small portion of the body and add up all the results; the total sum is known as the angular momentum of the body—or, as it is also called, the moment of momentum of the body about the axis. The principle of the conservation of angular momentum asserts that the angular momentum remains constant whatever internal changes may take place in the system, provided that there are no external forces acting. External forces would include friction and also the effect of other bodies not connected with the rotating body, but these are excluded in the example.

Let us now take a very simple illustration of the conservation of angular momentum which many readers have probably seen for themselves.

When a child is swinging on a rope attached to a lamp-post or some other vertical standard, it will be noticed that the speed of

the child increases as the rope coils around the upright. On the other hand, if the child starts off with part of the rope coiled around the standard and moves in such a direction that the rope is uncoiled, its speed will diminish as the length of the rope increases. The angular momentum of the child at any instant can be taken as its weight multiplied by its speed, and this again by its distance, measured horizontally, from the upright. Ignoring the friction of the rope, etc., when the child has started off swinging, its angular momentum should remain the same whatever the length of the rope may be; and when the rope becomes shorter, one factor in the above product is less, and hence there must be an increase in one of the remaining factors to ensure that the product of the three does not change. The weight of the child remains constant, and hence the variation must occur in its speed, which therefore increases as the rope shortens and decreases as the rope becomes longer.

A juggler spinning on a horizontal disc which can turn about a vertical axis can accelerate or retard his rate of spin by moving his arms. If he extends his arms horizontally he causes more weight to be placed at a greater distance from the axis of spin, and hence, if the rate of spin remained the same, the angular momentum of the system, juggler and disc, would increase. But this would be contrary to the principle enunciated above, because the movement of the arms comes under the category of "internal changes," and hence the rate of spin cannot remain the same, but decreases. For the same reason, when he drops his arms to his side the rate of spin increases.

The principle has a large number of applications in celestial problems, one of the simplest of which is found in the varying speed of the planets as they revolve round the sun. In the case of the earth this speed is nearly 18½ miles a second when the earth is at its mean distance—just over 93 million miles—from the sun. At the beginning of January it is nearer the sun by about 1½ million miles, and early in July it is farther from the sun by the same amount. In the former case, when it is nearer the sun, its speed must increase, and in the latter case, when it is farther from the sun, it must decrease, to preserve the constancy

of its angular momentum round the line drawn through the centre of the sun perpendicular to the ecliptic. The same thing applies to all the planets, and in the case of Mercury and Pluto very considerable variations of speed occur when these planets are in different positions in their orbits as they move round the sun, because their deviations from their mean distances from the sun are considerable.

The principle of the conservation of angular momentum has been responsible for wrecking some beautiful theories of the origin of our planetary system. It is remarkable that when it has destroyed one theory, and another has been formulated which has apparently avoided the angular momentum difficulty, it has been found later that this theory, too, becomes untenable owing to the same principle. A few examples of this will be given, from which the reader will see how very important the principle of the conservation of angular momentum has been in problems of cosmogony.

Kant's nebular hypothesis of the origin of our planetary system was published in 1775, in his *Allgemeine Natur-Geschichte und Theorie des Himmels*, and as Kant was primarily a philosopher, not a mathematician, it is not surprising that he started off with a fundamental error in his hypothesis. He postulated a large homogeneous nebula which in the course of time lost its homogeneity because it was composed of different elements which exercised different attractive powers. He believed that the movement of the heavier material towards the centre of the nebula, opposed by the expansion of the gases, generated lateral movements which produced a rotation of the whole nebula. In the first instance there was no rotation, so that the angular momentum of the nebula was nothing, and, in accordance with the principle just explained, it would always remain nothing, provided no extraneous forces acted on it. But Kant's view was that it could acquire angular momentum by its own internal movements—a view which was sufficient to condemn the whole hypothesis.

Laplace published his *Système du monde* in 1796, and devoted a portion to a consideration of the formation of the planets.[1] He

[1] A short account of Laplace's hypothesis is given on pp. 130–131.

avoided Kant's initial error and very adroitly postulated that the nebula was already in rotation, but the cause of this rotation was not explained. While he skirted the angular momentum difficulty in this way, he failed to avoid it in other ways, which were pointed out long after the publication of his work. In 1861 Babinet calculated the present angular momentum of the whole solar system and showed that it was very much smaller than the angular momentum of Laplace's rotating nebula. For this reason, and various other reasons as well, the Laplacian hypothesis was abandoned.

Sir James Jeans's tidal theory, first proposed in 1916 and subsequently modified in certain respects, postulated the disruption of our sun by a visiting star which made a very close approach. From the matter ejected by the sun, and also by the star, the planets and satellites were supposed to have been formed, and the theory was worked out in great detail. For many years it was generally accepted as the most feasible account of the origin of the solar system, and Sir James Jeans, believing that all other planetary systems in existence were formed in the same manner, calculated that only about one star in a hundred thousand was attended by planets at present. Many objections were raised against his theory, but the greatest objection of all emanated from the angular momentum difficulty—the very difficulty which Jeans set out to overcome and which he believed he had overcome. In 1934 Professor H. N. Russell showed that when the angular momentum of the planets per ton was considered, the whole theory became untenable. It would not be practicable, in the present work, to enter into the details of the calculations; it must suffice to say that astronomers regard the tidal theory as no longer feasible. Modifications of it have been suggested, but these are all open to serious objections, and other theories have been proposed, none of which has yet gained general acceptance.

In this brief sketch it is shown how very important is the principle of the conservation of angular momentum in one particular sphere; any theory of the origin of the solar system which ignores it is doomed to failure.

In dealing with the sun and his attendant planets and their

satellites we are dealing with a very parochial affair—merely a speck in the great cosmos. Are we justified in applying the same principle to the far-off stellar systems separated from us by hundreds of millions of light-years? If we extend the principle to them we are confronted by a difficulty which will be briefly dealt with at this stage.

It is believed that many thousands of millions of years ago the matter in the universe was distributed through space in the form of a diffuse gas with very low density. If the density were uniform it is difficult to see how stellar systems like the spiral nebulæ could have been evolved. There would have been a tendency for the diffuse gas to condense towards a centre under its own gravitation, but there would not have been any rotation or any segregation of the contracting gas into stellar systems. It is necessary, therefore, for the cosmogonist to make an *ad hoc* postulate—that the density of the original matter was not uniform, and consequently that there was a tendency for matter to collect in the denser regions. It may be objected that this *ad hoc* postulate is made merely to enable the cosmogonist to avoid difficulties, and this view can be admitted. The present writer has never been impressed with this assumption, which is basic for the theory of the development of various condensations, the masses of which are comparable with those of the spiral nebulæ. As the reader probably knows, the spiral nebulæ are merely aggregations of stars, just like our Galaxy, or Milky Way, and they are separated from one another by distances comparable with the distance of the Great Nebula in Andromeda, visible to the naked eye, and nearly a million light-years from us. The evolution of these condensations into stars has been outlined by the cosmogonist, and it is unnecessary to deal with the process in detail.

The spiral nebulæ rotate, just as our own Galaxy does, and indeed such rotation is a necessary step in stellar evolution. In its primeval stage the nebula, rotating and contracting under its own gravitational attraction, would increase its rate of rotation to preserve the constancy of angular momentum. Finally, a time would come when matter would be ejected from the equatorial regions of the lenticular-shaped mass and the nebula would break

up into a number of condensations, each of these in turn breaking up into groups of stars. Rotation is essential in the process of evolution, and the rotation originated, according to the cosmogonist, because the matter in the primeval nebula was not all of the same density. Owing to internal movements towards various centres of condensation where the matter was more dense, rotation would have been set up, and each condensation would finally have a rotation of its own. Such rotations still continue in the extra-galactic nebulæ—that is, in the spiral nebulæ—which are galaxies containing thousands of millions of stars, just like our own Galaxy.

Where did the original gaseous matter come from? Why should it not have had a homogeneous composition? Is it strictly correct to say that rotation would have started through differences of motion in various parts of the nebula? This suggestion is certainly open to question. If we imagine a large number of these movements in a nebula, then by the law of probability they would cancel one another's effects in producing rotation, so that rotation would not take place. Nevertheless, we know that the galaxies, including our own, are rotating at present; the portion of our Galaxy in which the sun is situated performs a complete rotation in a period of 225 million years—not a very long time when compared with geological periods. It almost seems as if the principle of the preservation of angular momentum, while holding for small portions of space, may require modifications when we deal with the macroscopic scale. It is, of course, possible to avoid this difficulty by postulating a rotation of the primeval nebula, just as Kant postulated a rotation for the comparatively small nebula out of which the sun and the planets were supposed to have been formed. But such a postulate only removes the difficulty to another sphere, because we want to know what caused the rotation. The assumption of rotation originating from a heterogeneous nebula is, however, not entirely satisfactory.

While writing this chapter my attention was drawn to a passage from *Science and the Unseen World*, the Swarthmore Lecture delivered by Sir Arthur Stanley Eddington in 1929, and a quotation

will be given because it tends to corroborate the view advocated here, that possibly certain laws which are applicable in a limited sphere lose their relevance when applied to the far-off regions of space. On pp. 9–10 of the work just referred to we read as follows:—

> Looking back through the long past we picture the beginning of the world—a primeval chaos which time has fashioned into the universe that we know. Its vastness appals the mind; space boundless though not infinite, according to the strange doctrine of science. The world was without form and almost void. But at the earliest stage that we can contemplate the void is sparsely broken by tiny electric particles, the germs of the things that are to be; positive and negative they wander aimlessly in solitude, rarely coming near enough to seek or shun one another. They range everywhere so that all space is filled and yet so empty that in comparison the most highly exhausted vacuum on earth is a jostling throng. In the beginning was vastness, solitude, and the deepest night. Darkness was upon the face of the deep, for as yet there was no light.
>
> The years rolled by, million after million. Slight aggregations occurring casually in one place and another drew to themselves more and more particles. They warred for sovereignity, won and lost their spoil, until the matter was collected round centres of condensation leaving vast empty spaces from which it had ebbed away. Thus gravitation slowly parted the primeval chaos. The first divisions were not the stars but what we should call "island universes" each ultimately to be a system of some thousands of millions of stars. From our own island universe we can discern the other islands as spiral nebulæ lying one beyond another as far as the telescope can fathom. The nearest of them is such that light takes 900,000 years to cross the gulf between us. They acquired rotation (we do not yet understand how) which bulged them into flattened form and made them wreathe themselves in spirals. Their forms, diverse yet

with underlying regularity, make a fascinating spectacle for telescopic study.

This description of the evolution of galaxies and stars from the primeval nebula, the spiral nebulæ acquiring rotation, "we do not yet understand how," is very interesting, and the confession of ignorance regarding the origin of the rotation is a contrast to the assertion of some cosmogonists that lack of homogeneity in the original nebula was the cause of rotation.

In dealing with the dynamics of the spiral nebulæ, Jeans admits that it is almost impossible to explain pure rotation dynamically in terms of known forces. He conjectures that the motions in spiral nebulæ must be governed by forces unknown to us, and even the interpretation of the spiral arms—permanent features of the spiral nebulæ—forms one of the most puzzling, as well as disconcerting, problems of cosmogony (*Astronomy and Cosmogony*, Chapter XIII).

This digression from entropy may seem unnecessary, but it has been undertaken to show that there are still some intractable problems when we come to deal with those far-off systems which resemble our Galaxy in structure and movement. The ordinary laws of gravitation seem inadequate to explain either structure or motion in some of these cases, and if we attempted to extrapolate from laws which hold in a limited portion of the universe we should find ourselves in a hopeless morass. The mathematician knows the dangers of extrapolating into the unexplored regions; the cosmogonist, too, is learning the same lesson. Almost certainly there exist unknown forces on whose nature we can only speculate, and much still remains to be done before Nature divulges many of her secrets.

Can we apply the same argument to the second law of thermodynamics? So far as experiment goes we know for certain that this law holds on our own planet. There would be rejoicing in the hearts of our engineers if it could be shown that the law is invalid, but there is little or no hope of such a revolutionary discovery, at least within our realm of experience. Are we justified, however, in applying the law universally, with all its

implications? Is the whole universe running down, and will it some day end its career? Was there a time when the universe was set going—a time which Whittaker identifies with creation? Is the law that entropy always increases universally valid?

Eddington discusses the question in *The Nature of the Physical World* (Chapter IV), and is adamant regarding its validity. He tells us that the law that entropy always increases holds "the supreme position among the laws of Nature." The chance against a breach of the second law of thermodynamics can, he says, "be stated in figures which are overwhelming." He adds an additional secondary law, which is not rigorously deducible from the second law of thermodynamics, but is accepted as fundamental in all modern studies of atoms and radiation. This law, which has proved to be one of the most powerful weapons of progress in such researches, is as follows:—

> *Nothing in the statistics of an assemblage can distinguish a direction of time when entropy fails to distinguish one.*

While other statistical characters might possibly be used to discriminate time's arrow, they can succeed only when entropy succeeds, and they fail when it fails. "So far as physics is concerned time's arrow is a property of entropy alone."

Jeans is equally emphatic on the matter. In *The New Background of Science* (Chapter VIII) he tells us that the universe will evolve through a succession of ever-increasing entropy, "until it finally reaches a state of maximum entropy." He admits, of course, that it is a question or probability, and if anyone should assert that the universe will move to a state of lower entropy, it would be impossible to prove that he was wrong. The odds against him, however, involve the very high powers of $10^{79}$, and thermodynamics generally disregards all such infinitesimal chances and announces its laws as certainties. Nevertheless, there is always a small risk of failure attached to every such law, and perhaps a better statement of the law would be that the chances of entropy decreasing are negligibly small.

It is not proposed that a frontal attack should be made on the validity of the second law of thermodynamics. To do so would

be utterly useless and would lead to no result except defeat. An indirect attack, however, may at least have the effect of causing physicists to reconsider the whole position, and perhaps to admit that other phenomena with which we are conversant, in particular in the realm of biology, suggest that the law of probabilities is not always a safe guide. We have already referred to the principle of the conservation of angular momentum, which has had such important applications in a number of dynamical problems, and which has been responsible for overthrowing a number of theories of the origin of the planetary system. Nevertheless, there are reasons for believing, as has been pointed out, that this principle may not hold when we come to deal with the evolution of galactic systems. In addition, Jeans suspects that in the spiral nebulæ there are forces entirely unknown to us, and he even conjectures that the centres of the nebulæ are of the nature of " singular points " at which " matter is poured into our universe from some other, and entirely extraneous, spatial dimension, so that, to a denizen of our universe, they appear as points at which matter is being continually created " (*Astronomy and Cosmogony*, Chapter XIII).

With such problems confronting us we might, with a considerable amount of confidence, question the validity of laws which are accepted without hesitation in our limited range of experience. We shall, however, look at the matter from a different point of view. To simplify the argument we may anticipate what follows by saying that there is nothing more improbable in the assumption that the entropy of the universe is decreasing, or at least that it can decrease, than there is in the assumption of a process of biological evolution, with all its ramifications.

Philosophical arguments on the origin and nature of life have an academic interest, but the biochemist conducts his research on the assumption that life is a special property of matter which must be arranged in a particular manner. Given favourable conditions, which are not yet fully understood, it is almost certain that life will appear as the result of highly complex chemical combinations. We can imagine an intelligent being, who happens to be the only form of life in existence, surveying the whole field

of chemistry and physics and estimating the probability that life will evolve from inert matter. This intelligent being will, we may believe, imagine that he is a special act of creation, and we need not disillusion him. We can endow him, if we wish, with the mental faculties of *Homo sapiens*, and hence we should be disposed to treat with due consideration the results of his calculations on the *a priori* probability of life in the lowest form appearing as a property of matter, and further, the probability that it will evolve along certain lines which a super-intelligence suggests to him as a possibility.

Surveying the whole field of physics and chemistry with the data now at the disposal of those who have devoted their life's work to physical science, this intelligent being might, if he felt so disposed, calculate the probabilities of various forms of life evolving, a description of the potential varieties being supplied to him by the super-intelligent being. It would require many volumes to cover the field of biology, and we shall restrict our inquiry to a few of the simplest and best-known cases.

A passage from *The Chemistry of Life*, by J. S. D. Bacon (Watts), will exemplify the point under discussion:—

> Among the vertebrates one can discern some of the differences existing between the groups, probably because more knowledge has been gained. Their nitrogen metabolism, particularly the end-products, forms a basis of classification which coincides with that established by structural and evolutionary methods. The following is a brief account of it:—
>
> The excretion of waste nitrogeneous products is a problem which can be solved comparatively easily by marine organisms. They have tissue fluids of approximately the same composition as sea-water, and therefore suffer no ill-effects from the fact that their skins are permeable to water. The end products of nitrogen metabolism can diffuse out through the skin, and are disposed of in this way. It appears, however, that vertebrates arose in fresh water, the backbone being perhaps an adaptation to life in running water, and they

have inherited tissue fluids of a salt content intermediate between fresh and salt water.

If a salt solution is separated from a less concentrated salt solution by a membrane which permits water but no salt to pass through, water will tend to pass through the membrane until the concentrations of salt on the two sides are equal. This is the case with all dissolved substances; sugar on one side will balance salt on the other if the appropriate concentrations are chosen. The phenomenon raises difficult problems for aquatic animals, which must have at least some permeable portions in the body surface through which to carry on respiration and absorb food. Consequently they tend to absorb water involuntarily when living in fresh water, and lose it involuntarily in sea-water.

They overcome the difficulty of life in sea-water by one of two methods; either by constantly swallowing sea-water and getting rid of the salts by a special process, or by allowing the nitrogeneous end-product urea to accumulate in their bodies until there is no longer a tendency for the tissues to lose water to the surrounding sea. One therefore finds in the cartilaginous fishes (e.g. skate, dogfish) a state of affairs in which urea, which in other vertebrates acts like a poison if allowed to accumulate, occurs as a normal constituent of the tissue-fluids.

When the vertebrates left the water and became breathers of air they encountered a similar problem. Their efforts to obtain oxygen from the air resulted in a constant evaporation of water from their lungs, so that even the reptiles, which by developing an impermeable skin made themselves independent of the marshy regions in which amphibia were forced to remain, were faced with the prospect of desiccation. Their marine ancestors had solved the problem by the retention of all water absorbed and the excretion of unwanted salts into the sea-water, but such a course was impossible in terrestrial animals. Then, too, urea had been a satisfactory excretory product for organisms which had ready access to water; the reptiles had to excrete *uric acid* instead, because

this requires less water for its excretion. Birds, which are regarded by zoologists as an evolutionary development from the reptiles, also excrete uric acid, and in both groups the young are hatched from water-tight eggs, in which the embryo excretes insoluble uric acid derivatives into a special chamber in the egg.

Mammals, on the other hand, developed a special method of concentrating the dilute urea solution which they excrete, and which in amphibia is not concentrated and so restricts the animal to damp regions. The kidney concentrates the urine by absorbing water from it, and enables the mammal to achieve nearly the same independence of water as is shown by reptiles and birds, but since the accumulation of urea inside a water-tight egg would use up some of the precious water, and might have toxic effects, the mammal embryo develops inside the body of its mother, who excretes the urea it forms. One thus sees in the nature of the nitrogeneous excretory products of vertebrates an order which corresponds to their evolutionary history. The aquatic forms excrete ammonia, urea, and certain other substances, which produce the characteristic fishy smell; the terrestrial forms no longer excrete ammonia because in the absence of plentiful supplies of water their excretory apparatus would lead to the temporary accumulation of dangerous amounts of this substance, which is toxic in comparatively small quantities. The amphibia and mammals excrete urea as the chief end-product of metabolism, and birds and reptiles excrete uric acid or related substances.

It has been found that the chick embryo developing inside the egg not only recapitulates its evolutionary past by developing at one stage a blood supply to serve gills which never form, but also recapitulates its biochemical evolution by first excreting ammonia, then urea, and finally uric acid. (Pp. 69–71.)

Our intelligent being, it will be assumed, is asked to calculate the probability of such extraordinary adaptations taking place,

and he will be told that there are certain factors operating to produce changes in the organism, among which environment (terrestrial) and perhaps extra-terrestrial influences, such as cosmic rays, have an important effect. When he has finished his computation he is then presented with a picture of the whole course of evolution for the last thousand million years, and is asked to find the probability that life should have assumed such a diversity of forms. Finally, he is told that as a result of this evolutionary process a species was developed with a brain possessing all the potentialities of that of the intelligent being, and the problem now is to find the probability that not only the earlier evolutionary process should have gone on, but that a brain like his own should have finally developed. It is doubtful whether the intelligent being would be able to express the probability in terms of high powers of $10^{79}$; it is more likely that he would dismiss the matter immediately as impossible—indeed, as much more impossible than the physicist believes the entropy of the universe can decrease.

This digression may seem irrelevant, more especially as it deals with biological phenomena, which, some will think, are on an entirely different footing from physical phenomena. If readers are convinced that life is something utterly distinct from matter and capable of existing independently of matter, probably the above argument loses its force. If, however, life is merely a property of matter, as most biochemists believe, then it seems that a theory based only on statistical evidence or on the law of probability may prove entirely misleading.

To return to the second law of thermodynamics. Is it possible that it has not a universal application? Is it true to say that, out in the depths of space, matter is being transformed into heat, and that some day the process will cease, when a dead level has been reached? Are we quite certain that the reverse process does not go on—the transformation of heat into matter? The probability against it may be enormous, looking at the problem from our very limited and restricted point of view, just as the probability of evolution may seem remote to the intelligent being, though evolution has been in progress for hundreds of millions of years. Instead of postulating the winding up of the universe

at some remote period, is there any *a priori* reason why there may not be an eternal rejuvenescence?

Here we must leave the problem, because further speculation will not assist us very much at present. Future discoveries may lay bare many hidden forces hitherto unsuspected, and may change the outlook of the cosmogonist who has built an imposing structure on the law of the increase of entropy. Until these hidden forces are known, it would be more in accordance with the scientific spirit to suspend judgment and to await the future with patience and hope.

Problems relating to Free Will or Determinism have arisen in recent years owing to developments in atomic physics. Strictly speaking, these do not lie within the province of astronomy; but many people have associated them with astronomy because two eminent physicists, who have written a considerable amount on the subject, happen to be astronomers as well as physicists. Sir Arthur Eddington and Sir James Jeans (both of whom died while this work was being compiled) have shown a great interest in the subject and have suggested that recent discoveries regarding the behaviour of the electron, and in other branches of physics, have very much weakened the argument in favour of a deterministic scheme in the universe. As the present writer has discussed this subject elsewhere, there would be no object in dealing with the controversy again in this book. Readers who desire a summary of the position, showing the arguments for and against a deterministic system, can consult the books [1] referred to. It may be necessary to add that, so far as the present writer is concerned, there seems no reason for changing our views on the subject of Free Will or Determinism. He is of opinion that atomic physics has contributed nothing to this controversial matter, and that further discoveries in atomic physics will leave the subject just where it has always been.

[1] *Free Will or Determinism* (Watts; 1937). *The Free Will Controversy* (Watts; 1942).

## CHAPTER XVIII

# THE EXPANDING UNIVERSE

WITH the aid of the 100-inch reflector at Mount Wilson it is possible to penetrate to a distance of about 500 million light-years, and, while probing this vast region produces samples only here and there, nevertheless these are of great value in determining the distribution of the galaxies. Although there is evidence of irregularities in their distribution in many parts of the sky, yet, taken on the whole, the average space density of the galaxies seems to be fairly uniform. Spectroscopic studies of galaxies as far off as 250 million light-years show that practically all of them are receding from us. This is the interpretation of the observed shifting of the spectra towards the red; and the amount of this Döppler shift is proportional to the distance of the galaxy. Galaxies about one million light-years away, like the Great Nebula in Andromeda, recede at a speed of 100 miles a second, and those at a distance of ten million light-years recede at a speed of 1,000 miles a second, and so on.

If this rate of recession continued, and if galaxies were ever observed at a distance of 2,000 million light-years, they would appear to be receding from us with a velocity greater than that of light. In accordance with the view of modern physics nothing can move faster than light; hence difficulties confront us if the rate of recession does continue in this way. When the 200-inch telescope has been installed it will be able to reach galaxies 1,000 million light-years distant, and, if the relation just referred to still holds, it is conceivable that some other interpretation of the Döppler shifts will be forthcoming. If, on the other hand, the relation fails to hold, it is possible to regard the universe as still expanding. It should be noticed that the galaxies are not only running away from us; they are all running away from one another, as if they were once fairly close together and were dispersed by an explosion or by some other means, their motions still continuing after the lapse of many hundreds of millions of years.

Alternative hypotheses have been advanced to explain the red shift. We know that dust, gas, electrons, etc., are found throughout space, and it is possible that light passing through these loses some of its original energy. Red light represents less energy than blue light, as the energy of a quantum of radiation is proportional to its frequency, and red light has less frequency than blue light. While some astronomers are prepared to accept this explanation, others are convinced that there is no evidence for this "tiring" of light—at least not to the extent required by the amount of the Döppler shifts. It is hoped that the 200-inch telescope will settle the controversy on this point.

The conception of an expanding universe is a result of the relativity theory, and a considerable amount of work has been done on this subject by different cosmogonists. The problems involved are beyond the scope of this book, and as there is a lot of speculation on the subject, no useful purpose would be served by dealing with it here in detail. Eddington's conclusions are interesting, but they are not accepted by all astronomers, and in fact there is considerable doubt regarding the validity of some of his deductions. He thought that the universe started off with a radius of about 1,000 million light-years and that it contained an amount of matter equal to about $10^{22}$ suns. If this matter were spread evenly throughout the universe its density would have been about $2 \times 10^{26}$ grammes to the cubic centimetre. This is probably ten to twenty times the present density, so that the linear dimensions of the universe have more than doubled since it began. This gives its present radius as more than 2,000 million light-years. More recently he suggested 5,000 million light-years, and if this figure is adopted the total number of galaxies in this space is about $3 \times 10^{11}$. If the universe started from a statistically uniform equilibrium state, the time required to reach the present state is about 90,000 million years, and 8,000 million years ago it ceased to be possible for light to travel right round the universe. Eddington considered that the extreme limit of 90,000 million years is the result of a fantastic extrapolation, and preferred to say that the system could be traced back for 30,000 million years without straining credulity. However,

neither of these values allows sufficient time for the formation of condensations in a uniform primordial distribution of matter from which the galaxies developed. For this and for other reasons, he expected modifications of the theory and also of the time estimates.[1]

It should be emphasized that what can be observed with the 100-inch telescope does not constitute the "universe," though it is sometimes confused with it. As de Sitter says :—

> After all, the "universe" is an hypothesis, like the atom, and must be allowed the freedom to have properties and to do things which would be contradictory and impossible for a fine material structure. What we observe are the stars and nebulæ constituting "our neighbourhood." All that goes beyond that, in time or in space, or both, is pure extrapolation. The conclusions derived about the expanding universe depend on the assumed homogeneity and isotropy—i.e., on the hypothesis that the observed finite material density and expansion of our neighbourhood are not local phenomena, but properties of the "universe." It is not inconceivable that this hypothesis may at some future stage of the development of science have to be given up, or modified, or at least differently interpreted.
>
> Our conception of the structure of the universe bears all the marks of a transitory structure. Our theories are decidedly in a state of continuous, and just now very rapid, evolution. It is not possible to predict how long our present views and interpretations will remain unaltered and how soon they will have to be replaced by perhaps very different ones, based on new observational data and new critical insight in their connection with other data.[2]

Our hope for the future lies in the fact that each phase of scientific advance has contributed something that is preserved for

[1] Eddington's speculations have appeared in a number of works. See *The Expanding Universe* and also *Monthly Notices of the Royal Astronomical Society*, 104, 1944, 200.

[2] *Kosmos*, pp. 133–4.

the next phase. This process will continue unless man's insanity ends it—and this is not an impossibility. Eddington's remarks in this connection are apposite. He says :—

> As for man—it seems unfair to be always raking up against Nature her one little inadvertence. By a trifling hitch of machinery—not of any serious consequence in the development of the universe—some lumps of matter of the wrong size have occasionally been formed. These lack the purifying protection of intense heat or the equally efficacious absolute cold of space. Man is one of the gruesome results of this occasional failure of antiseptic precautions.[1]

[1] *New Pathways in Science.* Epilogue.

## CHAPTER XIX

# HOW THE HEAT AND LIGHT OF THE STARS ARE MAINTAINED

THE solar system consists of a massive central body—the sun—around which revolve a number of smaller and less massive bodies known as the planets. The atom [1] is conceived to be a miniature solar system, the sun being replaced by the *nucleus* of the atom and the planets by the *electrons* which revolve around the nucleus. There is one very important difference between the conditions existing in the solar system and in the atom. In the case of the solar system the planets revolve around the sun in nearly the same plane; Pluto's orbit deviates most from the plane of the ecliptic, this deviation amounting to over 17°. (The minor planets are not included in the category of planets at the moment; some of them move in orbits with considerable inclinations to the plane of the ecliptic.) In the case of the electrons revolving around the nucleus, their orbits do not necessarily lie even approximately in the same plane, these orbits being inclined to one another at various angles.

The nucleus carries with it one or more charges of positive electricity. In the case of the hydrogen atom the nucleus carries only one charge of positive electricity and it has one electron revolving around it, the mass of the nucleus—the *proton*—being about 1,850 times that of the electron. If the atom should lose its electron—and this frequently occurs—it becomes positively electrified; the reason being that the electron, which is simply a negative charge of electricity, neutralizes the positive charge on the nucleus, so that normally the atom is electrically neutral, but when an electron is ejected from the atom the positive charge is no longer neutralized.

When we deal with atoms other than hydrogen certain complications arise, but it is unnecessary to deal with these except in

[1] Some figures dealing with the sizes and masses of atoms are given at the end of the chapter.

a few cases which are relevant for the present purpose. The manner in which the electrons are distributed around the nucleus in atoms other than hydrogen will now be considered.

The helium atom has two electrons revolving around the nucleus, and in order that these should be neutralized—that is, in order that the helium atom should be unelectrified—the nucleus must carry two charges of positive electricity. The lithium atom has three electrons, and the nucleus has three units

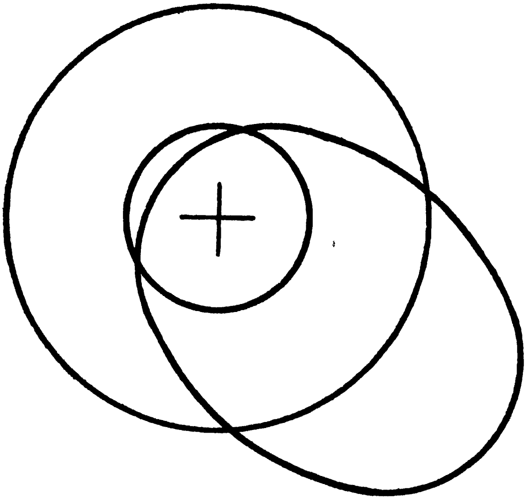



FIG. 12.—A PICTORIAL REPRESENTATION OF THE ATOM.

An atom is believed to consist of one or more electrons revolving round a central nucleus, marked +, which is the focus of the ellipse in which the electrons revolve. They can also revolve in circles.

of positive electricity. The beryllium atom has four electrons and the same number of positive charges attached to the nucleus, and so on with the elements in increasing order of atomic numbers until we come to uranium—the heaviest of all elements[1]—which has 92 electrons revolving around the nucleus, which, in turn, carries the same number of positive charges. (The atomic number is the number of positive charges in the nucleus of an atom.)

[1] Heavier elements, such as neptunium and plutonium, are now produced artificially.

While the electrons revolve around the nucleus in various planes, their arrangement, so far as numbers are concerned, is not haphazard. It is believed that for the maintenance of stability there must be two electrons in the first ring—or *shell*, to be more correct, since " ring " denotes the same plane for the orbits of the electrons. The next two shells should each contain eight electrons, and then there should be 18 electrons; but there are complications in the case of shells beyond this, and we shall limit our survey to atoms with less than four shells.

The chemical characteristics of an atom are determined neither by its nucleus nor by the electrons in its inner shells, but by the electrons in the outer shells. To illustrate this point take the case of sodium, which has 11 electrons: two in the first shell, eight in the second, and one in the third. It has been pointed out that there should be eight electrons in the third shell if stability is to be maintained, and as a result of this arrangement the sodium atom is unstable. (The word " unstable " is used in a very restricted sense, implying that the atom is in a condition to unite with another atom. Strictly speaking, " stable " and " unstable " are applicable only to the outer shells of the atom.) We shall now see what follows from this instability.

In the case of the chlorine atom there are 17 electrons, the first shell having two and the next shell eight; but the third shell has only seven—one less than the number required for stability. Suppose the chlorine atom approaches the sodium atom, what will take place? The chlorine atom requires one electron to produce stability, and the sodium atom, which has one electron in its outer ring, wants to get rid of this electron to produce stability. The result is that each atom can render assistance to the other, and hence the chlorine atom annexes the electron from the outer shell of the sodium atom, thus achieving stability for both atoms. The forces of electric attraction will make the two atoms hold together, the result of the union being a molecule of sodium chloride or ordinary table-salt. The electric attraction arises from the fact that the sodium atom loses an electron and hence is positively charged, and at the same time the chlorine atom acquires an electron and hence is negatively charged.

Many other examples could be given, but the case of chlorine and sodium will be sufficient to illustrate the principle operating when chemical affinity exists between the atoms of various elements.

Nothing has been said about the nature of the nucleus of the atom except that the nucleus of the hydrogen atom consists of the simple unit known as a proton. In the case of other atoms the nuclei have more than one proton, and it will be easier to understand the nature of the atomic nucleus if something is said about radio-activity.

Radio-active substances emit one or more of three kinds of

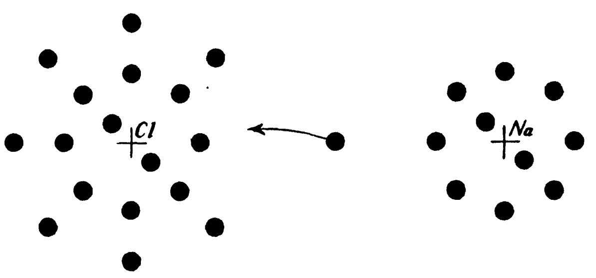



FIG. 13.—ARRANGEMENTS OF ELECTRONS IN DIFFERENT ATOMS.

The outer shell of chlorine has seven electrons, and requires one more electron for stability. The outer shell of sodium has one electron, and, if this were lost to the atom, stability would ensue, because the next inner shell has eight electrons. Hence there is an affinity between the atoms of chlorine and sodium, as described in the text.

rays. The first of these, known as the $\alpha$-rays, consist of particles each of which is the nucleus of a helium atom. Each such particle has a positive charge double that which is carried by the hydrogen nucleus; that is, each particle has two charges of positive electricity. As these are shot out from radio-active substances the positive charges attract electrons, and hence when they encounter other atoms in their flight, sometimes at speeds as high as one-tenth that of light, they remove electrons belonging to these atoms. Instead of being rays or the *nuclei* of helium atoms, they now become ordinary helium atoms, which differ from $\alpha$-rays merely in having two electrons revolving around the nucleus.

What happens to the radio-active substance which emits these $\alpha$-rays ?

The atomic weight of helium is 4, and as the $\alpha$-rays are the nuclei of helium we should expect that the atomic weight of the element shooting out these rays would decrease by 4. (It should be noticed that, owing to the small mass of an electron compared with a proton, which is the nucleus of hydrogen, the simplest of all atoms, the addition of a few electrons to, or their removal from, an atom makes practically no difference to the mass of the atom.) The expected decrease in the atomic weight of the substance emanating the $\alpha$-rays is just what takes place. Thus radium, with atomic weight 226, sends out $\alpha$-particles and becomes radon, the atomic weight of which is 222. The dream of the alchemists has been realized in modern times, and the transmuta-

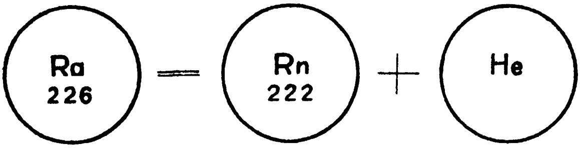



FIG. 14.—DISINTEGRATION OF RADIUM.
Radium disintegrates spontaneously into radon and helium.

tion of one element into another is continuously taking place in nature.

Radio-active substances also emit $\beta$-rays, which are simply electrons, and these move much faster than the $\alpha$-rays ; sometimes their speed is about 99 per cent. that of light. In addition, $\gamma$-rays are emitted by radio-active substances; these differ from the other two classes of rays in being not particles, but of the nature of light-waves. They will be referred to later when we deal with certain nuclear transformations.

In addition to the protons and electrons there are also neutrons, which were discovered by Chadwick in 1932. These have nearly the same mass as the protons, but, as their name implies, they are electrically neutral and do not carry a charge of positive electricity, as do the protons. The discovery of the neutron has, to a certain extent, clarified our conception of the nucleus, which can be

regarded as composed of protons and neutrons. Take the case of lithium, with atomic weight 7. It is believed that its nucleus consists of 3 protons and 4 neutrons, and as a neutron has practically the same mass as a proton, the mass of the lithium nucleus must be seven times that of the hydrogen nucleus. Each of the three protons has a positive charge associated with it, and hence, to neutralize these charges, there must be three electrons revolving

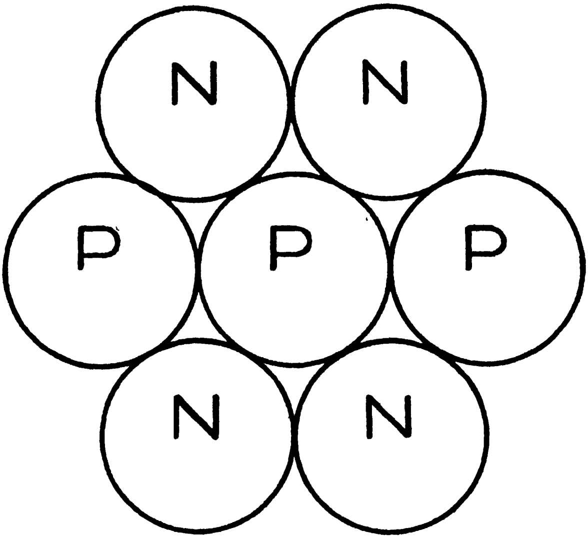



FIG. 15.—STRUCTURE OF THE ATOMIC NUCLEUS.

The nucleus of the atom is believed to consist of protons and neutrons, each of the former carrying a positive charge of electricity, and each of the latter being neutral—*i.e.*, carrying no charge.

round the nucleus. The same applies to other nuclei of the various elements; these are also composed of protons and neutrons, the number of electrons being the same as the number of protons, and the atomic weight being the total number of the protons and neutrons in the nucleus. It has been pointed out that the chemical properties of atoms depend on the electrons in their outer shells, not on their nuclei. If a neutron is added to the nucleus of an atom it will increase the atomic weight of the

atom by 1, but will not affect the number of electrons revolving around the nucleus. The addition of the neutron does not increase the number of positive charges carried by the nucleus, and hence does not require that an additional electron should be added. This explains why we often find "isotopes" of various elements; the isotopes differ in atomic weight, but have the same chemical characteristics, the difference in atomic weight being due to the nucleus of one isotope having one or more extra neutrons, and the chemical characteristics being due to the arrangement of the electrons in the outer shells, this arrangement remaining unaltered when extra neutrons are added to the nucleus.

Another particle, discovered in 1932 by Anderson, an American physicist, while he was investigating the nature of cosmic rays, was named the *positron*. Its mass is the same as that of the electron, but it has a positive, not a negative, elementary charge. It is very unstable, and its life is only about a hundred-millionth of a second, after which it combines with an electron, the charges cancelling each other. The mass is annihilated and an equivalent amount of energy is produced which appears in the form of $\gamma$-rays.

The bombardment of the nuclei of atoms by protons or neutrons has devastating effects on the atoms encountered. Neutrons are able to move through a much greater distance than protons before they strike the electrons revolving round the nucleus. The reason for this is as follows.

Since a proton carries a positive charge, it attracts electrons of atoms which lie in its path, at the same time losing a certain amount of its energy of motion by the collisions. Neutrons, which carry no electric charge, can pass through the skeleton of an atom without much probability of colliding with an electron; hence their velocity is not reduced so rapidly as is that of the protons. Our chief interest at present is with the collision of a proton or a neutron with the *nucleus* of an atom, and a simple example of the effect will now be given.

When a proton strikes the nucleus of an atom of lithium the result is the production of two helium atoms. The proton has a mass practically identical with the atom of hydrogen, the atomic weight of which is 1; and as the atomic weight of lithium is 7,

the mass of the two combined is 8, which is equivalent to the mass of two helium atoms (the atomic weight of helium is 4). When a proton strikes the nucleus of an atom of nitrogen, with atomic weight 14, the result is an atom of helium and an atom of carbon, the atomic weight of carbon being 11. Many other such transformations take place, and they are all accompanied with the liberation of an enormous amount of energy. As an example of the amount of energy liberated take the above case of lithium. If 15 grains of this metal were disintegrated in a second, energy equal to 300 million horse-power would be liberated. Slow-scale transformations of nuclear energy are now accomplished by artificial methods, and the disintegration of the atom by means of the cyclotron and other methods is carried out in various parts of the world. We need not here describe the different forms of apparatus employed for this purpose, as our interest lies in the large-scale transformations continuously going on in the interior of the stars, including our sun.

The temperature of the outer layers of the sun is about 6,000° C., but at the centre of the sun the temperature is probably 20,000,000° C. (This temperature cannot, of course, be measured directly, but on theoretical grounds the physicist is able to compute the temperatures in the interior of the sun and other stars.) At such a temperature the atoms lose their electrons, which dash about at very high speeds, waiting to be captured by some of the protons which have lost their electrons. In a minute fraction of a second after this annexation the electrons are again torn from the protons by the terrific heat, and the process is repeated indefinitely. Innumerable rays of short wave-length result from all this turmoil, but by the time that the radiation makes its way to the surface of the sun, or other star, the wave-length has become longer and we receive the radiation either in the form of the ordinary heat and light waves emitted from the surface of the sun or in the form of the light-waves from the surfaces of the stars.

It is believed that about one-third of the sun's mass consists of hydrogen and that other stars contain about the same proportion. The transformation of this hydrogen into helium has been shown

in comparatively recent times to be a possible source of the enormous output of energy in the form of heat and light from the sun and other stars. In the case of the sun the reaction can be briefly described as follows.

A collision between a proton and the nucleus of a carbon atom produces the lighter isotope of nitrogen, with the liberation of energy in the form of a $\gamma$-ray. This reaction has been obtained in the laboratory, and so the result described is not mere theory. The nucleus of the isotope of nitrogen then emits a positron and becomes the nucleus of the heavier carbon isotope, which, in turn, is struck by a proton and becomes ordinary nitrogen with the liberation of energy in the form of a $\gamma$-ray. The nucleus of the ordinary nitrogen atom collides with a proton, and the oxygen isotope is produced with a $\gamma$-radiation. This oxygen isotope then emits a positron and becomes a heavy isotope of nitrogen, which is struck by a proton and transformed into ordinary carbon and the helium nucleus. The cycle then recommences, the carbon nucleus being struck by a proton and thus initiating the same sequence of changes. The whole process can be summarized by saying that, as a result of the enormous temperature, hydrogen has been transformed into helium, and that carbon and nitrogen act as catalysts in the transformation. The word *catalysts* employed here has not quite the same meaning as it has when it is used by the chemist, but it will be seen that carbon and nitrogen remain during the process, while the hydrogen gradually disappears, being transformed into helium. When this transformation has been completed we must not expect the sun to supply us with much more heat and light.

It has been estimated that the reaction described above requires about 5,000,000 years for a complete cycle, but as myriads of cycles are beginning and others are ending every second, there is no interruption in the output of the sun's energy. For reasons which it would take too long to explain, the temperature in the interior of the sun is actually increasing at present, though this increase is a very slow process. Looking into the future we can conceive that the temperature of the sun will become so high that life on the earth and on Mars (if life exists there) will slowly

disappear. During this stage of increasing temperature the hydrogen content is being used up, and when all the hydrogen has been transmuted into helium no more fuel will be available to maintain the sun's output of heat and light. As the sun will then contract, owing to the reduction of heat in the interior, a certain amount of energy will be generated by this contraction and some output of heat will be maintained for a time. Gradually shrinking to smaller and smaller dimensions, and emitting a small fraction of the light and heat that were previously emitted, the sun will finally approach his death, and collapse into a white dwarf—a very small star with an enormous density (some white dwarfs have a density 30,000 times that of water, and some considerably more than this), and from this state there is no recovery. The death of the sun would be final in this case unless by an extremely improbable coincidence it collided with another star, in which case the energy of motion would be partly converted into the form of heat and light, and the sun would be rejuvenated for a time.

If this view, which has gained a certain amount of credence recently, is valid for the future of the sun, and other stars as well, we can speculate on the future of our planet. The present increasing temperature of the sun will very gradually turn the oceans into vapour, so that the earth will be enveloped in a canopy of clouds—something like the planet Venus as she appears when viewed through a powerful telescope. Probably the last traces of life on the earth will be in the form of very low micro-organisms which can endure a high temperature, but even these will ultimately succumb to the intense heat.

After a very long period, when the hydrogen content has been used up and the sun has started to shrink, the earth will become cooler, and it is possible that life might again appear, though what form it would assume is a matter of pure conjecture. Owing to the relatively rapid changes in temperature—the cooling process taking place much more quickly than the rise in temperature while the hydrogen was being used up—it is possible that life would be much more adaptable to changing conditions than it was previously. Its final fate would be the same, but in this

case it would succumb through cold, not because of intense heat. The earth would still continue its revolutions round the sun, which would ultimately be too cold to supply any heat to our planet. Perhaps if an astronomer on a planet belonging to some other star looked at the solar system with a super-telescope he would be able to see a white dwarf round which revolved a number of small bodies. He might be specially interested in one of these, which would probably present the appearance of a sphere of ice and snow, and he might even speculate on the possibility of life having existed on such a planet in the remote past. If he knew, as he possibly would, all that the modern physicist knows about the past and future of white dwarfs, he would probably meditate on the ephemeral nature of life which appeared for a time on various planets (including his own) scattered about through the universe, and which would inevitably disappear to return no more.

While this view follows from our recent conceptions of the manner in which stellar energy, in the form of heat and light, originates far down in the interior of the stars, it would be premature to accept it as final. In Chapter XVII the possibility of rejuvenescence was considered, and though the weight of opinion at present is decidedly against such a view, the stream of knowledge has often turned on itself, and some day rejuvenescence may be an accepted doctrine. Here we leave this subject, on which one can offer only tentative speculations, as convincing evidence is not available.

## Note on the Dimensions and Masses of some Elementary Particles

In the description of very small quantities negative powers of 10 are used. Thus $10^{-1}$, $10^{-2}$, $10^{-3}$ mean one tenth, one hundredth, one thousandth, and so on. As the metric system will be used, the following figures showing the connection between this and the English system will be helpful:—

1 centimetre is 0·4 inch.
1 gramme is approximately 15 grains.

The atom of hydrogen has a mass of $1 \cdot 5 \times 10^{-24}$ gramme. The mass of other atoms can be obtained by multiplying these figures by the atomic weight of the element.

The electron has a mass of 1/1850 of the hydrogen atom, and hence the mass of the electron is $8 \times 10^{-28}$ gramme. Protons and neutrons have practically the same mass as the hydrogen atom.

The size of an atom varies because some of the electrons in the outer shells are in unstable orbits and are annexed at times by other atoms, and, in addition, the electrons alter their distances from the nucleus. Normally the diameter of a hydrogen atom is about $10^{-8}$ centimetre. The proton and the electron are nearly the same size, but there is some doubt about their actual dimensions. It is believed that their diameters are about $10^{-5}$ that of the atom; so if we express the ratio in volume, we can say that the electron has a volume $10^{-15}$ that of the atom. The earth's diameter is about $4 \times 10^{-5}$ the diameter of the orbit in which it moves round the sun, so that an atom is comparable with the solar system, the sun representing the nucleus and the planets the electrons. While this comparison is very rough, it will give the reader an idea of the relatively large amount of empty space in the atom. Incidentally it may be pointed out that the sun has a mass more than a thousand times that of Jupiter; so, when masses are considered, there is also a comparison between the solar system and the particles composing an atom.

The speed of the electron, as it moves in its orbit round the nucleus, varies with its distance from the nucleus. In the case of the normal hydrogen atom this speed is about 1,400 miles a second, and the electron makes 7,000 million million revolutions each second.

CHAPTER XX

# CONCLUSION

Our survey of the development of astronomical science from the early period of man's history up to modern times has shown the profound influence which astronomy has had on human thought and action. When astronomy was studied primarily for astrological purposes there was the recognition of some occult power exercising an influence on the affairs of men, and this astral fatalism was sometimes transferred to cities and communities. Although this doctrine, if fully accepted and made a basis for conduct, would have had a paralysing effect on social and material progress, it does not appear that the results were always as devastating as might be expected. Among the Babylonians there was remarkable progress in the social life in spite of the influence of astrology, which only tends to prove that it is possible to hold certain beliefs which exercise little influence on the practical affairs of life. It is probably true that a great many people to-day believe in astrology, but only a small proportion of these shape their lives in accordance with its pronouncements. Another matter regarding astrology among ancient people is important; astrology was closely associated with State functions, and it is quite possible that the cult was largely limited to the wealthier classes, who could pay for the luxury, while the great majority of the people were influenced by it only to a very small extent.

As might be expected, astronomy first developed in Eastern countries, where the brilliant stars appeared to be close to the earth and were almost regarded as some part of the equipment of the human theatre. In the early periods of astronomy there does not appear to have been any conception of a natural order, the erratic movements of the planets being attributed in some cases to supernatural agencies. It is not surprising that astrology should flourish where such beliefs prevailed, though, as has just been remarked, real interest in the subject may have been confined to a minority of the people.

Knowledge of the movements of the heavenly bodies was often limited to the priest-astronomer, who used his superior learning to enhance his power at the temples, particularly in Egypt. While the priests found it advantageous to keep the people in ignorance of astronomical matters, nevertheless they served a useful purpose in agricultural countries, in which the seasons for sowing must be known with a fair degree of accuracy. The priests were able to predict the time when the Nile would overflow its banks—a matter of supreme interest for the Egyptians—and hence their assistance was of the utmost importance for those who depended on a fertile soil for supplying their material needs.

The speculations of various Greek astronomers assisted in the advance of astronomy, but unfortunately, after the death of Ptolemy in the second century, the progress of astronomy in Europe almost ceased for many centuries, and it was left to the Arabians to maintain an interest in the subject. Although they contributed very little to theories or new ideas in astronomy, their observations proved useful. Arabic learning percolated through Europe, and many Arabic works on different scientific and philosophical subjects were translated into Latin. Some of these were Arabic translations of Greek books, which were thus made accessible to European scholars. When the Turks captured Constantinople, in 1453, and Greek scholars were dispersed over Europe, there was a great revival of interest in science and the way was prepared for the transition from the ecclesiastical to the secular ideal. Copernicus was a leader towards new ideas which had far-reaching consequences not only in astronomy, but also in men's outlook on religion and in other ways as well.

The conception of an inherent natural order—encouraged by the mathematical work of Newton—replaced the conception of continuous control and interference on the part of an external power, although traces of the survival of this latter belief can still be found. With this conception there also arose the view of the universe as something infinitely larger than anything that had been previously contemplated. Bruno's doctrine of an infinite universe with no localized heaven—a natural development of the Copernican system—had important implications which are of no

interest to us to-day. But in the days of Bruno the Abode of the Blessed was localized beyond the sphere of the stars and was an essential part of the universe. The doctrine of an infinite universe was thus a denial of the unity of creation, and this explains the reason for the fierce opposition of the Church to such teaching. Another reactionary force was also in operation, and even at the present time its effects are felt.

The Christian religion incorporated many crude astronomical conceptions into its teaching, these conceptions being derived from primitive Hebrew astronomy. When some of these conceptions were shown to be untenable, the Church set itself against those who advocated views based on scientific observation. Thus St. Augustine, in the fifth century, was the author of the doctrine that nothing is to be accepted save on the authority of Scripture, and he upheld, as an article of faith, the view that no antipodean inhabitants existed. If they did, they could not be descendants of Adam and it would be impossible for them to hear the Gospel, because everyone knew that the torrid zone was an impossible barrier between north and south.

Many similar childish views prevailed, among which may be noticed the favourite Church doctrine that Jerusalem was the centre of the earth. This idea was based on Ezekiel v. 5, and had a place in Dante's cosmogony. Pilgrims were even shown a pillar on the north side of the holy places, and in the middle of the city, which marked the exact centre of the earth. Although there was considerable opposition to the new views advocated by Copernicus and others—persecution, torture, and even death, often awaiting the more enlightened who boldly proclaimed their views—truth finally prevailed.

From the days of Newton, astronomy made rapid progress and men were impressed by a view of the universe which appeared to conform to a few general principles and was not directly controlled by a capricious Being. The feeling that law and order prevailed, and that the cosmos seemed to work largely on mechanical principles, opened a wider vista for those whose outlook had previously been very circumscribed by theological tenets. Active opposition to the propagation of new truths decreased,

though the ban placed by the Roman Church on the works of Copernicus was not removed until 1835.

Within the last few decades the advances in astronomy have been unprecedented in the whole history of scientific development. This rapid progress is largely due to the work of the physicist, without whose assistance many of the most important discoveries in astronomy could not have been made.

Recent developments in atomic physics have tended towards unity in our conception of the universe. The atom is now regarded as a microcosmic planetary system, and this view has been very valuable in explaining many stellar phenomena, including a recent theory of the enormous output of energy in the form of heat and light. The matter throughout the universe is believed to consist of the elementary particles with which the physicist experiments in the laboratory—protons, electrons, neutrons, positrons, etc.—and everywhere there appears to be a unifying principle underlying all phenomena. The old mechanical view of the universe—a view which regarded it as a closed system—has been disturbed in comparatively recent times by the progress of atomic physics, and a few physicists have adopted the view that we can no longer regard the universe as closed. The controversy on the problem still continues and probably will continue unless some new discovery throws more light on the subject or shows that the divergence of opinion may be due merely to different ways of looking at the problem.

Until fairly recent times it was believed that planetary systems were extremely rare, and that life was therefore limited to a few bodies on which conditions for its existence happened to be favourable. Within the last few years it has been discovered that two comparatively close stars have bodies of a planetary nature revolving round them. If these stars had been far away the planetary bodies could not have been detected, and it may be presumed that there are many stars which have planets associated with them; but they are too far away from us to be discovered.

No longer do we regard the solar system as the sole theatre of the drama of life; myriads of other such systems may exist. With our enlarged conception of the immensity of the cosmos

there has arisen also an enlarged conception of the universe of life. Not only is there a unity extending from the infinitely small to the infinitely great—from electrons to stars and galaxies—there is also a unity in the realm of life itself. Who can say what diverse forms it may assume on myriads of other worlds? What mind can comprehend the heights to which its intelligence may soar? If we believe, as we are practically forced to do, that life develops from non-living matter, largely because of some fortunate combination of elements, and evolves into many forms under external stimuli of whose nature we are still very ignorant, this fact challenges some of the old traditional views of design and purpose in the universe. Such a challenge necessarily calls for profound modifications in the philosophies which were based upon earlier astronomical knowledge.

The progress of astronomy has produced very far-reaching results in various features of the Christian religion. That the founder of Christianity adopted the views of astronomy current in his days is quite clear, and as certain dogmas of the Christian faith depend on teaching which is based on a discarded cosmology, perplexity and confusion in Christendom have ensued. Attempts at restatement to adapt doctrines to the outlook of the present age have not been very successful, and in some cases such attempts have caused more confusion and difficulties than they have removed. More serious than the effect of advancing knowledge on dogmas is its effect on the ethics of Christianity. If, as seems extremely likely, some of the ethical principles of Christianity were advocated by its founder because he accepted the crude Jewish cosmology and also believed that the old world was rapidly approaching its end, a new dispensation being imminent, can those principles be regarded as binding on men of every race and at all times? This problem has become much more acute in the complexities of modern civilization, and many are doubting the efficacy of Christianity to solve the difficulties inherent in society as organized to-day. It is almost certain that this problem will become more intractable in the near future, and it is possible that some of our ethical code will undergo considerable modifications.

Every religion, every philosophy, is based ultimately on a con-

ception of the cosmos, and recent discoveries have given us conceptions fundamentally different from those which prevailed when various religions and philosophies of the past were developed. We have, therefore, to adjust our view of the processes of the universe and of the place of human destiny to a new framework of knowledge.

In many directions science has tended to become national in its outlook and scope—an attitude largely due to the exigencies created by two world wars. Astronomy, however, being less applicable to military purposes than any other science, has largely escaped this influence. During the six years of destruction which accompanied the second world war the discoveries in astronomy were communicated to all countries which had representatives on the International Astronomical Union. A Central Bureau has been responsible for informing the various astronomical institutions all over the world when new and important discoveries were made in astronomy. It is difficult to imagine that similar communications would ever be made under the same conditions when new discoveries occurred in such branches of science as chemistry, physics, metallurgy, and numerous others. Astronomy stands far above national interests and material gain, and it can be truly described as the oldest and most sublime of all the sciences.

Men of science in every branch have wonderful opportunities for encouraging a better and happier international relationship. The words of Sir Richard Gregory at the conclusion of his work, *Religion in Science and Civilization*, are apposite in this connection, and they are capable of a universal, not merely a national interpretation :—

> Science can only continue to render its fullest service to the community as the relations between the general scientific worker and the general citizen are harmonized and the purposes and methods of science are widely understood. In the establishment of such a sympathy, a nobler type of citizenship becomes possible, adequate to defend us against the dangers to which civilization is exposed and to build a social order on an ethical system worthy of the limitless powers which the increase of natural knowledge has placed in the hands of men.

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